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EFFECT OF DIGITAL WORD SIZE ON PRECISION OF DATA RECOVERY FROM FIELD INSTRUMENTATION

Electromechanical Systems of New Mexico, Inc.
P.O. Box 11730
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12 November 1980

Topical Report for Period 15 April 1979—12 November 1980

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With the onset of new technological advances in microelectronics, it is possible to acquire data in digital form directly in the field as opposed to recording analogue data in the field then in a separate laboratory process convert to digital data.

Most of the DNA field event data include responses from accelerometers, pressure gages, velocity gages and stress-strain measurements. The effect

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20. ABSTRACT (Continued)

of the precision of a digital data acquisition system on the data and the integrals is the subject of this report from the point of view of digital data analysis using various word sizes.

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PREFACE

This document was written under Contract DNA 001-79-C-0298 for the Defense Nuclear Agency. It is the hope of the author that the material contained herein will serve as a guide to the R&D scientific community for future data acquisition systems and data analysis.

A special acknowledgment is extended to Dr. R. A. Shunk for his consultation and comments on the writing of this document.

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INTRODUCTION

In the past decade rapid advances have been taking place in microelectronics and related areas. In particular, digital data acquisition systems are being designed so that the data are gathered, processed and displayed all in one operation in the field. In the DNA blast and shock community, the emphasis is on data obtained from the responses of accelerometers, pressure gages, velocity gages and stress-strain gages to transient inputs generated by explosive detonations. It is important that the digital recording systems be so designed that data precision be one of the main considerations. These considerations must also include data which come from the integration of the accelerometer and pressure gage outputs to obtain particle velocity and impulse. The effect of the precision of a digital data acquisition system on the data and the integrals is addressed in this report from the point of view of digital data analysis with varying word size.

STATEMENT OF PROBLEM

With the advent of microelectronics, fiber optics, microcomputers, etc. came also the idea of how to "improve" data gathering techniques. In the past it has been the exclusive practice to monitor transducer outputs and record the analogue data from them on magnetic tape. In a separate process, these data signals are converted to digital information and stored on magnetic tape for further analysis using digital computer techniques.

With the new innovations in microelectronics, it is indeed now possible to take an analog-to-digital (A/D) system into the field and acquire data in digital form directly in the field. The components of such a system require only a relatively small physical area. The latest and least expensive of these types of system use an 8 bit data word and up to 16 bits on the address bus. Double precision can be utilized so a 16 bit data word is available at the cost of time resolution and larger buffers, memories, etc.

A very important problem of concern is data resolution when converting from analogue to digital information. Digital data resolution is related to the word size which is a basic parameter in the design or use of any A/D recording system.

Of the A/D data processing systems encountered in the past, some organizations have used an 11-bit plus a sign word to record information, although 7, 13, 15 and 18-bits plus a sign have been utilized at other facilities.

The word size is critical, particularly if the data are integrated. This will be demonstrated using a typical accelerometer signal from air blast induced ground shock.

SIMULATION PROCEDURES

It has been observed quite regularly in data analysis that an accelerometer record, when integrated, may have an unexplained offset in the velocity data. It is generally argued that the bias is inherent in the gage, thus data analysis techniques are used to "correct" the data.

It is possible that the bias may not be caused by the transducer alone but that upon analyzing the digital data, the word size was not large enough to resolve the details of the signal, so a critical analysis of this problem is presented.

The first step is to derive acceleration data that are typical of field-event data. It was decided that data from the DNA sponsored high explosive test, MISERS BLUFF II, would be used as a model.

A CDC 7600 computer was used and a code was written in FORTRAN to simulate the A/D system conversion of the signal to digital information which was then integrated.

The data signal was modeled after the acceleration and velocity traces similar to those in Figure 1. The simulated data are shown in Figures 2, 3 and 4 for the acceleration, velocity and displacement, respectively. The digitizer was operating at 0.8 msec/point with a 10 μsec window.

It should be noted that the CDC 7600 is a 60-bit machine, so the simulated data words for the MISERS BLUFF data are much more precise than any of the words used in the A/D simulator.

To digress, data acquisition systems record data as voltages where a designated engineering unit value equals a certain voltage. As an example,

the data acquisition system may be set up for ± 5 volts full scale, comparable to an acceleration of ± 2000 G's. This information is needed before analog-to-digital processing can be accomplished.

In the A/D process, the analogue voltage is converted to a binary word. In the case stated above, ±2000 G represents the total G range, so if a digital word size is to be 7 bits plus a sign (i.e., $\pm(2^7 - 1) = \pm 127$ counts), then the resolution between adjacent words or counts for a noise free signal is:

$$\frac{2000}{127} = 15.75 \text{ G's/count.}$$

This means that the digitized word (in counts) for the analogue signal does not change unless a change of 15.75 G's occurs. This is where an error can be introduced. It is seen that the peak and large G data points are inaccurate (i.e., 1000 G can be in error by about 1%) but for any signal point below 15.75 G, the data indicates 0 G. (In the integration of acceleration, this can affect the velocity as we will see.)

In Table 1 it is shown that the greater the word size the better the resolution can be. A full range of ± 2000 G is assumed as in the previous example. Ideally, a 17-bit word would represent 0.015 G or about 15 parts/million.

Table 1

BITS (Plus a Sign)	Digital Value	G's/Count*
7	127	15.748
8	255	7.843
9	511	3.914
10	1023	1.955
11	2047	.977
12	4095	.488
13	8191	.244
14	16383	.122
15	32767	.061
16	65535	.031
17	131071	.015

* Based on ± 2000 G maximum.

However, in the design of an A/D system one must be practical yet aim for maximum tolerable efficiency. In this light, the results from the simulation technique can now be viewed.

SIMULATION RESULTS

The simulation was set up for +5 volts corresponding to +2000 G's with a signal which peaks at ~600 g, a not uncommon situation in a field experiment. The original acceleration trace is shown in Figure 2. The data in Figure 2 were integrated twice to get velocity and displacement as shown in Figures 3 and 4.

The A/D simulator code is designed to always work with the original derived acceleration data as input and proceed to change the number of bits in a word to obtain different word sizes. The word size in the analysis went from 7 bitsplus a sign to 17 bits plus a sign and the results are shown with their respective velocities and displacements in Figure 5 thru 37.

As a worst case, note the 7-bit (plus a sign) word, Figures 5-7, which is presently in the DNA Field Command equipment inventory. The acceleration trace suffers greatly in the low G area which is proven out in the velocity where not only the peak velocity is in error but a severe zero off-set is observed. The displacement, of course, is in rather sad array, not indicating any tie to reality. The 8-bit (plus a sign) word, Figures 8, 9 and 10, show the same problems.

The 9-bit (plus a sign) word has improved the data slightly and more of the acceleration is displayed in the low G range (Figure 11). The 10-bit (plus a sign) word is beginning to show more of the original velocity as is displayed in the first integral in Figure 15.

The 11 and 12-bit (plus a sign) data words (Figures 17 thru 22) are showing more promise, especially when observing the first integral. The amplitudes are close to the original but there is still a noticeable zero offset in the velocity. The 12-bit word simulation displacement in Figure 22 is 180 cm vs the 200 cm in the original data which bears this out.

The 13 and 14-bit plus a sign data words are still improving the data display as can be seen from the respective velocity and displacement traces (Figures 24-25 and 27-28). Still there is a noticeable zero offset in the velocities.

The 15-bit plus a sign word has almost completely duplicated the original data. Comparing the acceleration, velocity and displacements (Figures 29 thru 31), it is clear that data resolution has been maintained. The zero offset has all but disappeared. As a further study, 16 and 17-bit (plus a sign) words were simulated, Figures 32 thru 37, and even though there are signs of increased improvement, there is not significant change from the 15-bit to the 17-bit plus sign.

It should be noted that this simulation was set up for ± 2000 G equal to a full range of ± 5 volts with a peak signal level of -600 g recorded. Full range means the maximum recording system capability. The problem, of course, gets much worse if ± 10,000 G is used for full range and the signal has a peak of 1000 G. Thus, the design of a data acquisition system must include in its criteria for use what type of data are to be recorded, how they are to be processed, what precision is expected in the processed data and what portion of the maximum range is to be allocated to the predicted signal.

CONCLUSIONS

From the graphs and the brief discussion of the simulation, the more significant bits that are used in the data words the better the processed data precision. However, judging from the integrals of the data, it is plausible that a 12-bit plus a sign word is marginal and that a 15-bit plus a sign word is satisfactory for typical ground motion acceleration data. Ideally, of course, is a 17-bit plus a sign word or better which would deal with nearly any problem including signals smaller than predicted.

The problem of an offset in the first integral is apparent from the graphs. Even in a 12-bit word, there are errors introduced. Comparing the displacement of the original data trace (Figure 4) and the displacement from the 12-bit acceleration data (Figure 22), the error is significant. At 0.4 sec. the displacement should read 161 cm, but is only 155 cm. The original maximum displacement is about 200 cm and is about 178 cm for the 12-bit simulation and that is with a positive zero shift in the data. A baseline correction would reduce the displacement even more. Good agreement in displacement begins to occur around the 14-bit simulation. Here (Figure 28) at 0.4 sec. the displacement is about 161 cm which is correct. The final displacement value is about 195 cm, still not quite up to the 200 cm mark but adequate for engineering purposes. Table 2 gives a summary of peak velocities, offset and displacements vs. the word size for the signal used here.

The 14-bit plus a sign word simulation, however, has preserved the single and double integration to within 3% which is probably adequate for most purposes.

Table 2

Word Size (BITS) (Plus a Sign)	Peak Velocity (.25 sec) cm/sec	Zero Offset	Displacements CM (0.4 sec)	(Final)
7	200	Yes	0	-700
8	410	Yes	62	-192
9	700	Yes	100	- 82
10	825	Yes	139	148
11	900	Yes	150	165
12	950	Yes	155	178
13	950	Yes	159	185
14	975	Yes	161	195
15	975	Small	161	200
16	975	Small	161	200
17	975	No	161	200
Original	975	No	161	200

RECOMMENDATIONS

Reviewing the graphs and from the discussions in the text, it is recommended that before experimenters decide upon A/D data processing equipment they should critically look at what results are desired from a test. It is important to keep in mind the type of transducers, the responses involved, the precision desired in the data and the integrals or derivatives and other quantities involved in the gathering of meaningful data.

Current A/D data acquisition systems should be critically reviewed in order to decide if they meet the requirements for a certain experiment.

Clearly, 7 and 8-bit(plus a sign) word systems are not adequate for typical ground motion measurements and only a system with a 14-bit (plus a sign) word or better would be deemed satisfactory. This could be obtained by paralleling eight bit systems with a large gain differential between them or going to double precision. This introduces another set of electronics problems which will not be addressed at this time.

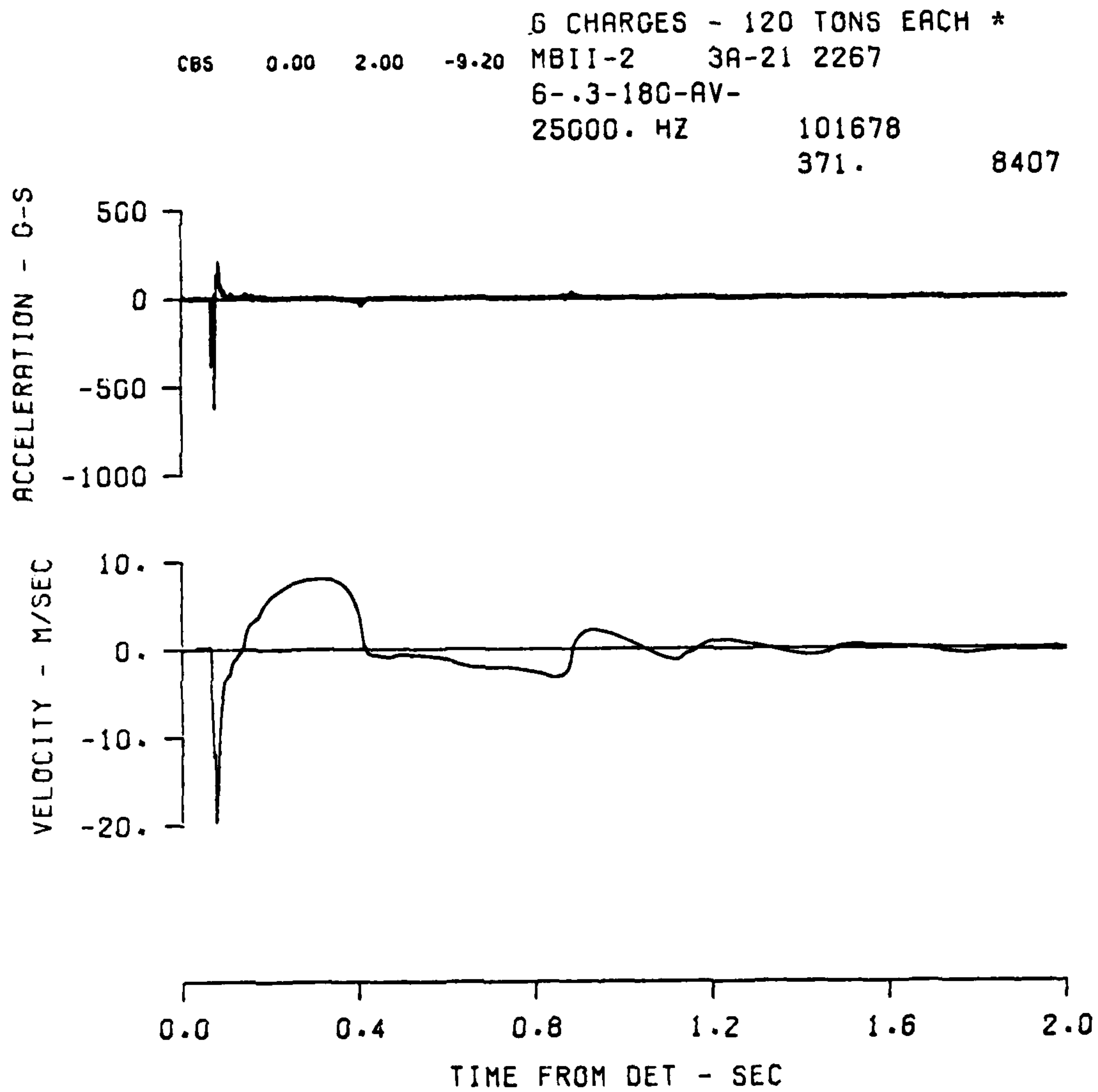

Figure 1. MISERS BLUFF-II, Acceleration and velocity vs time.

*MISERS BLUFF series; Phase II: Ground shock and airblast measurements data report/ by D.Q. Murrell, J.H. Stout. U.S. Waterways Experiment Station, 1979.

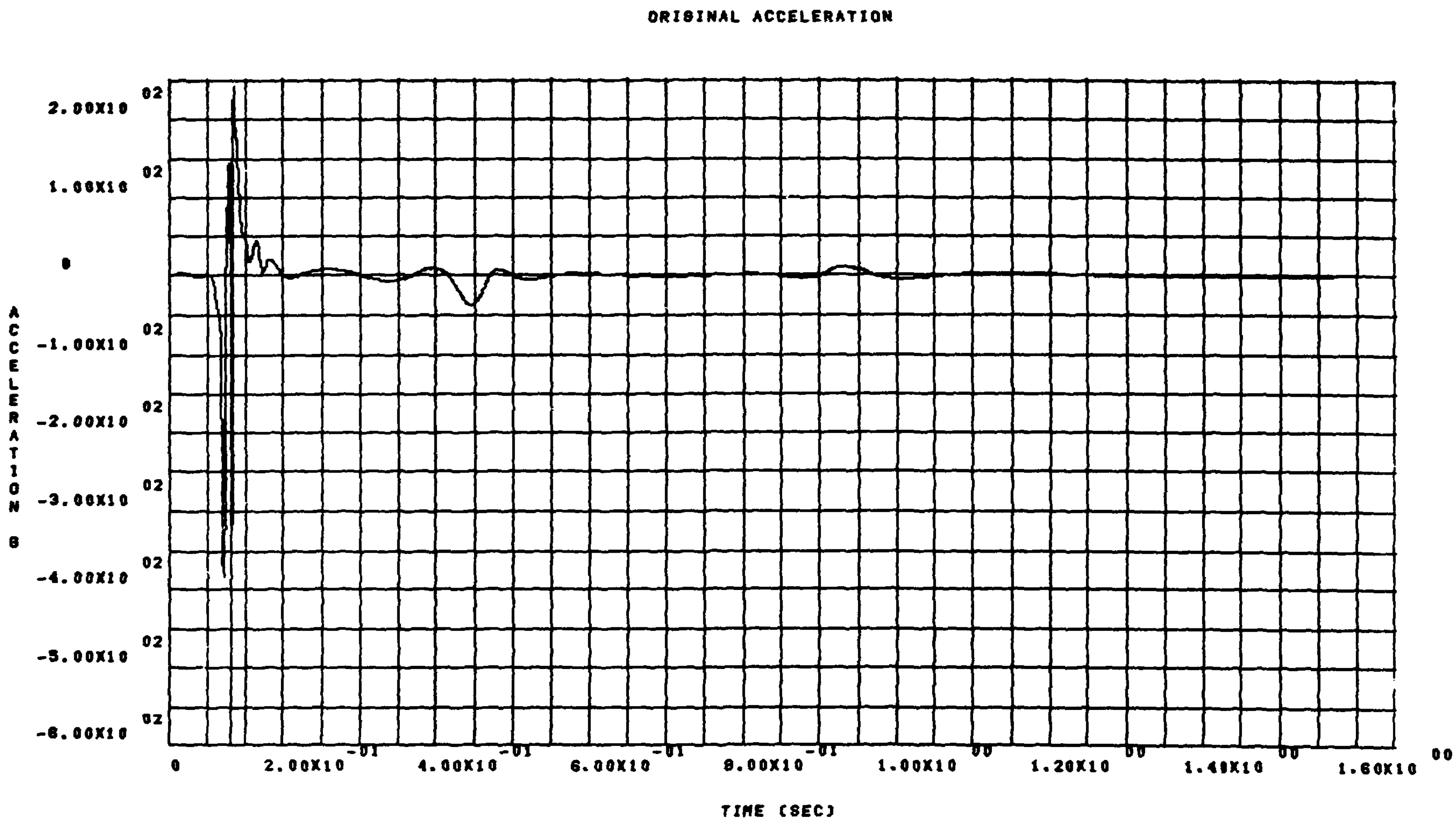

Figure 2. Simulated acceleration vs time.

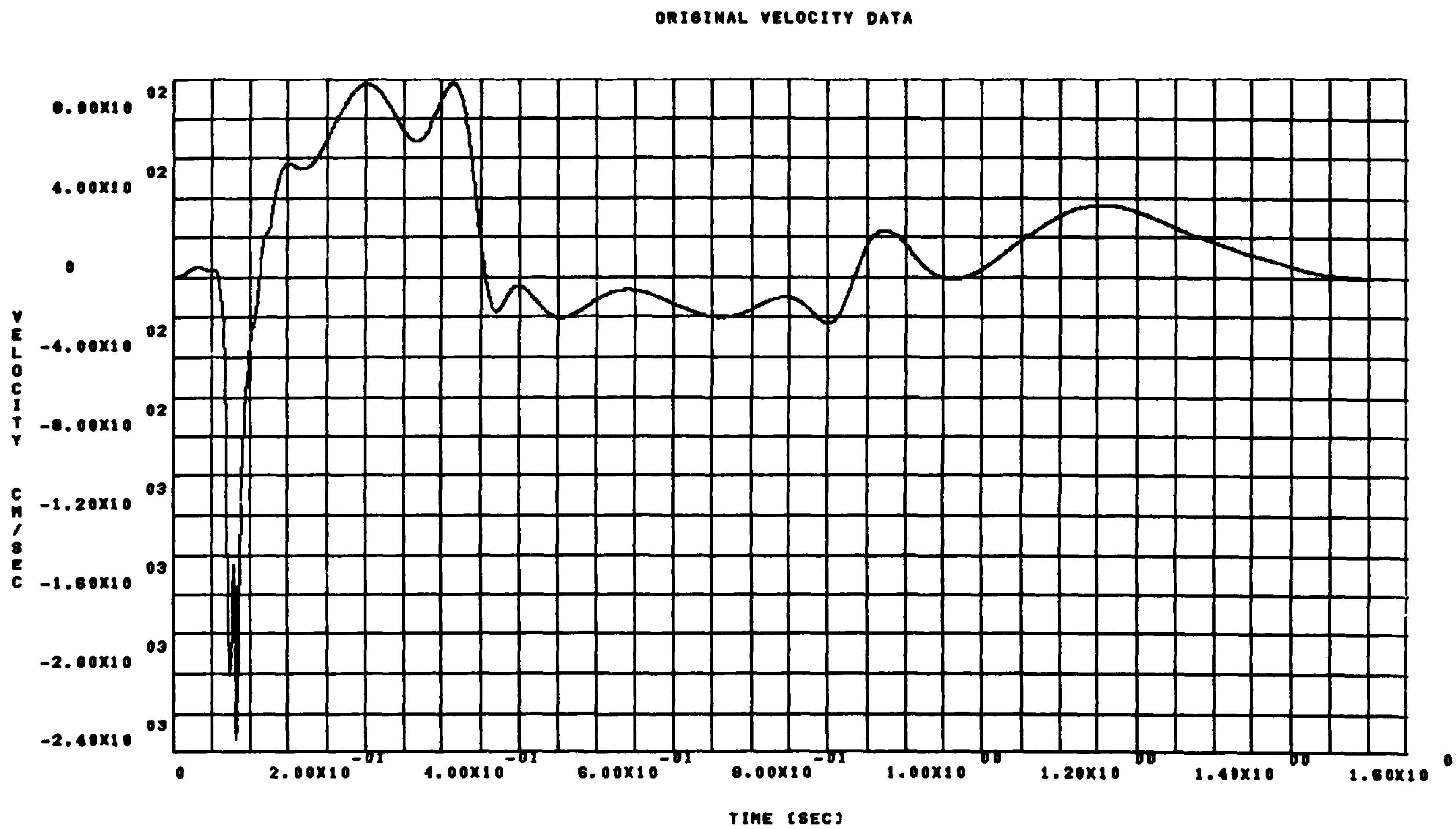

Figure 3. Integrated simulated acceleration.
Velocity vs time.

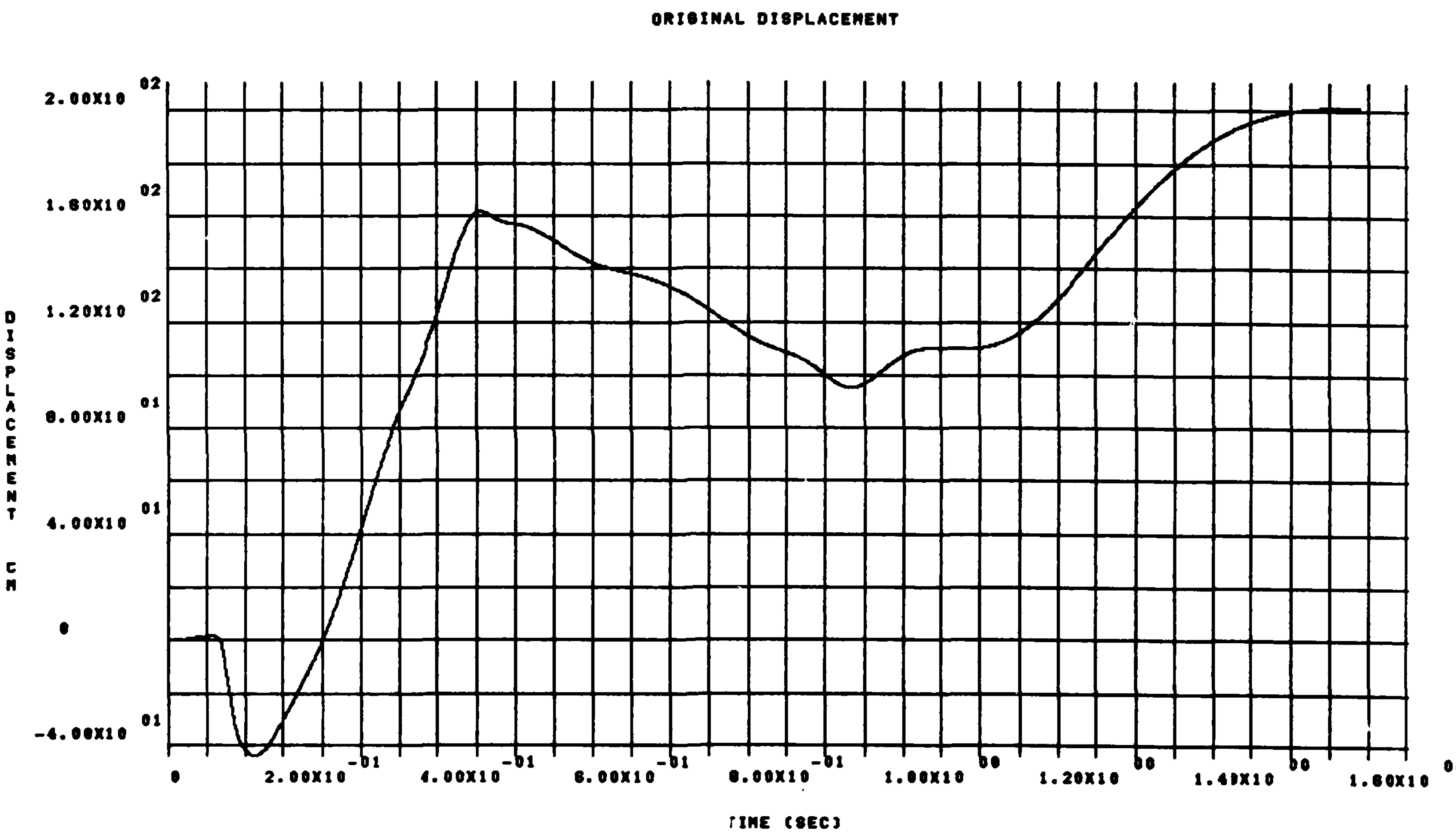

Figure 4. Double integration of simulated acceleration.
Displacement vs time.

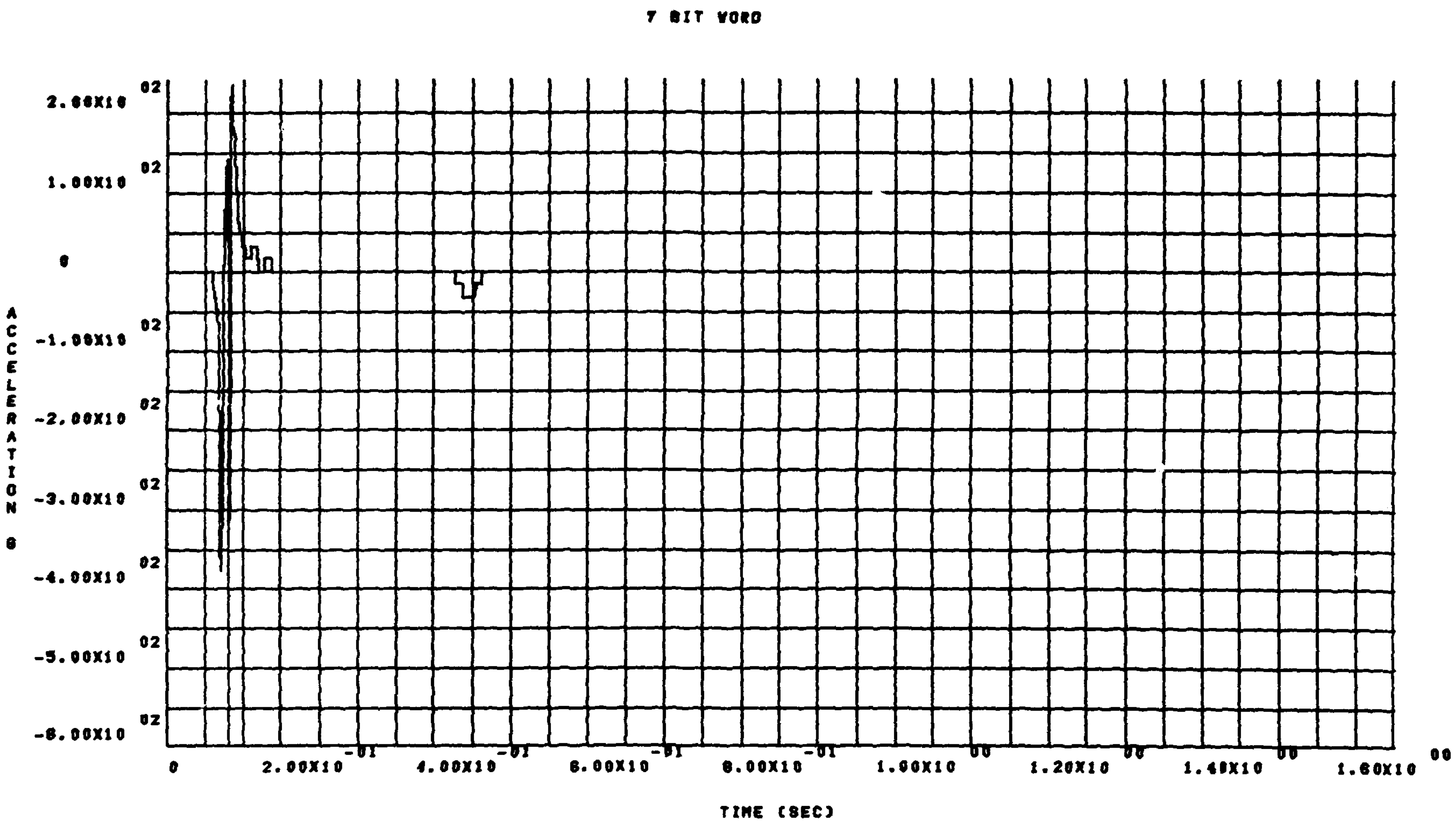

Figure 5. Acceleration vs time.
7 significant bits word size.

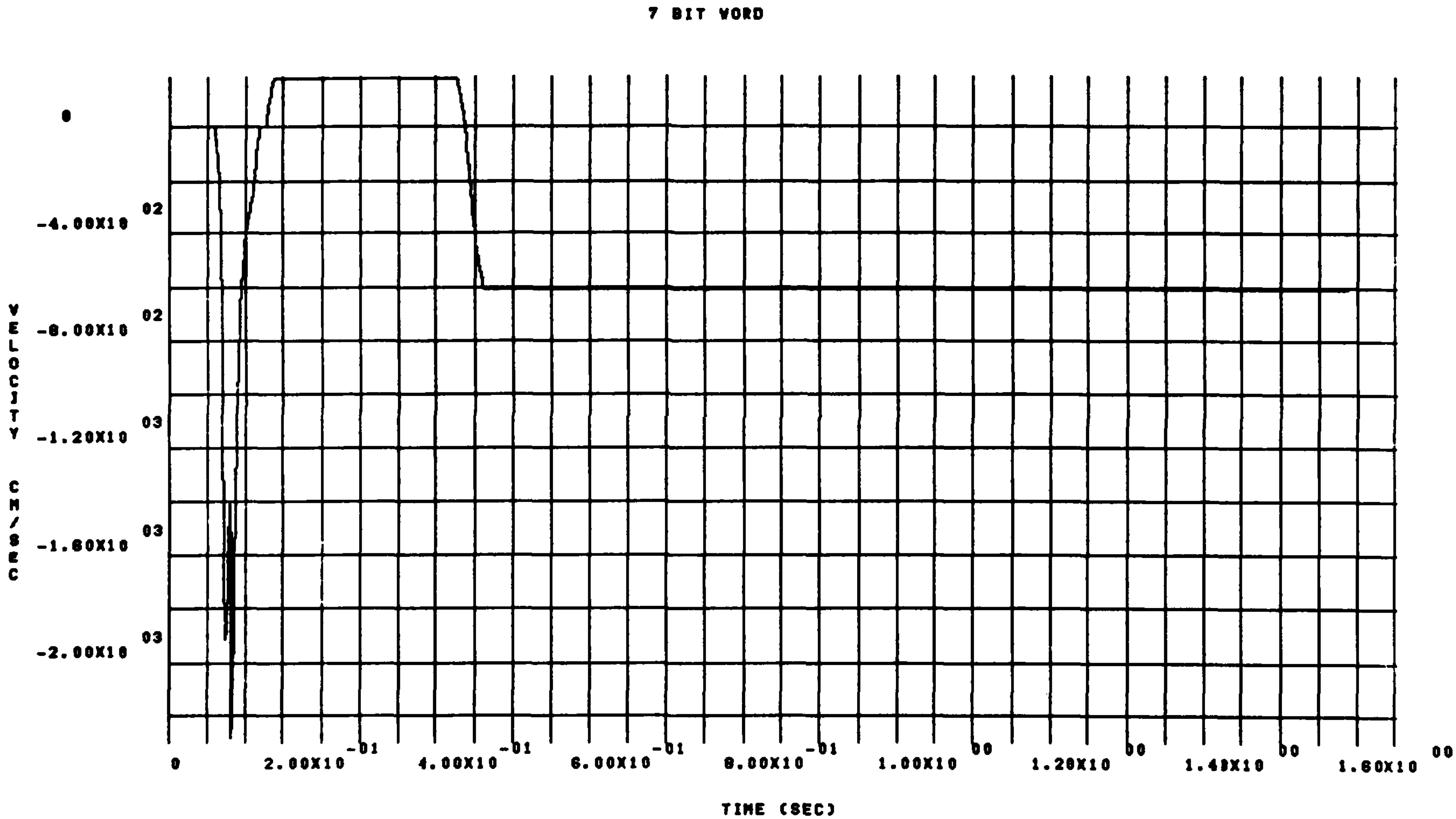

Figure 6. Velocity vs time.
7 significant bits word size.

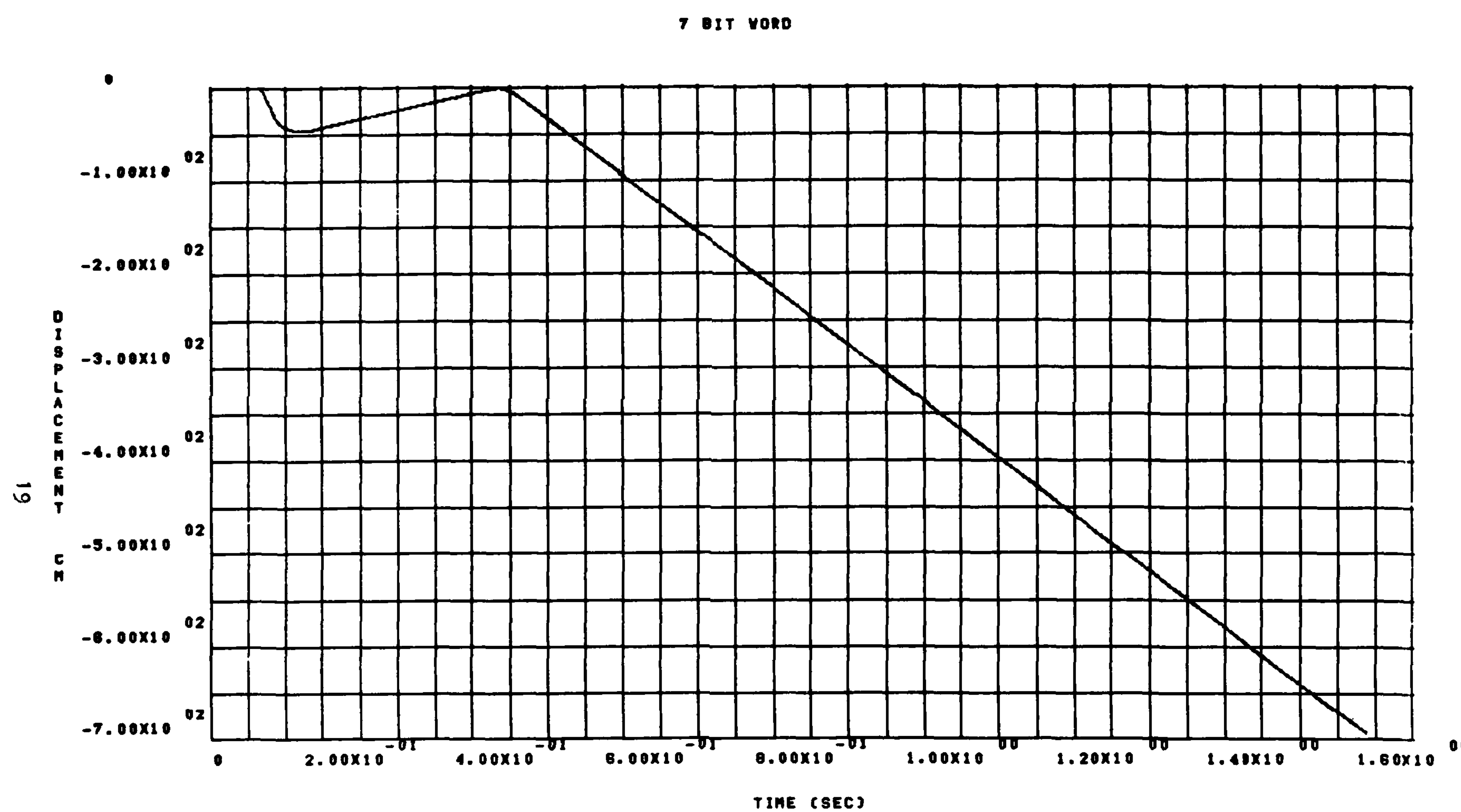

Figure 7. Displacement vs time.
7 significant bits word size.

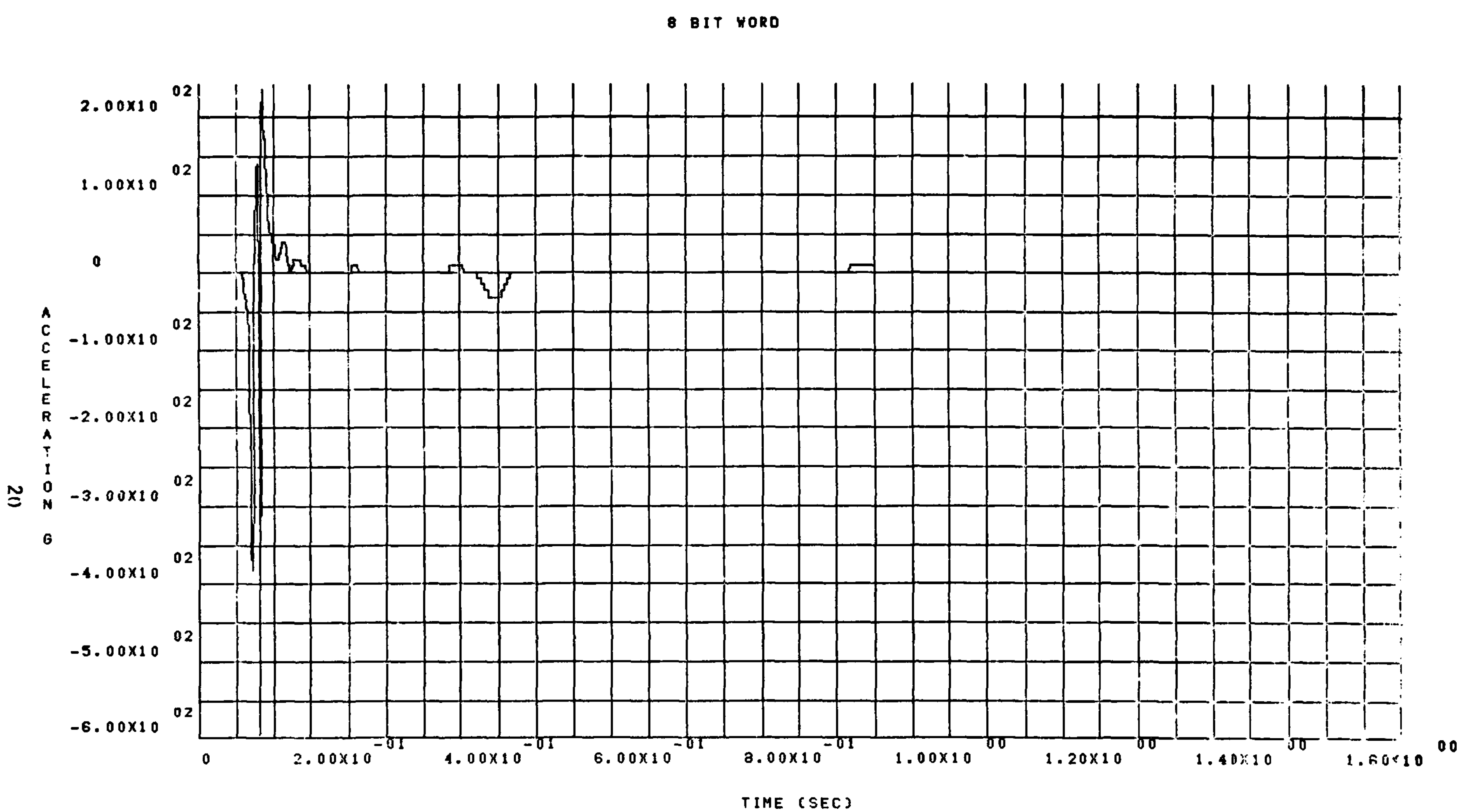

Figure 8. Acceleration vs time.
8 significant bits word size.

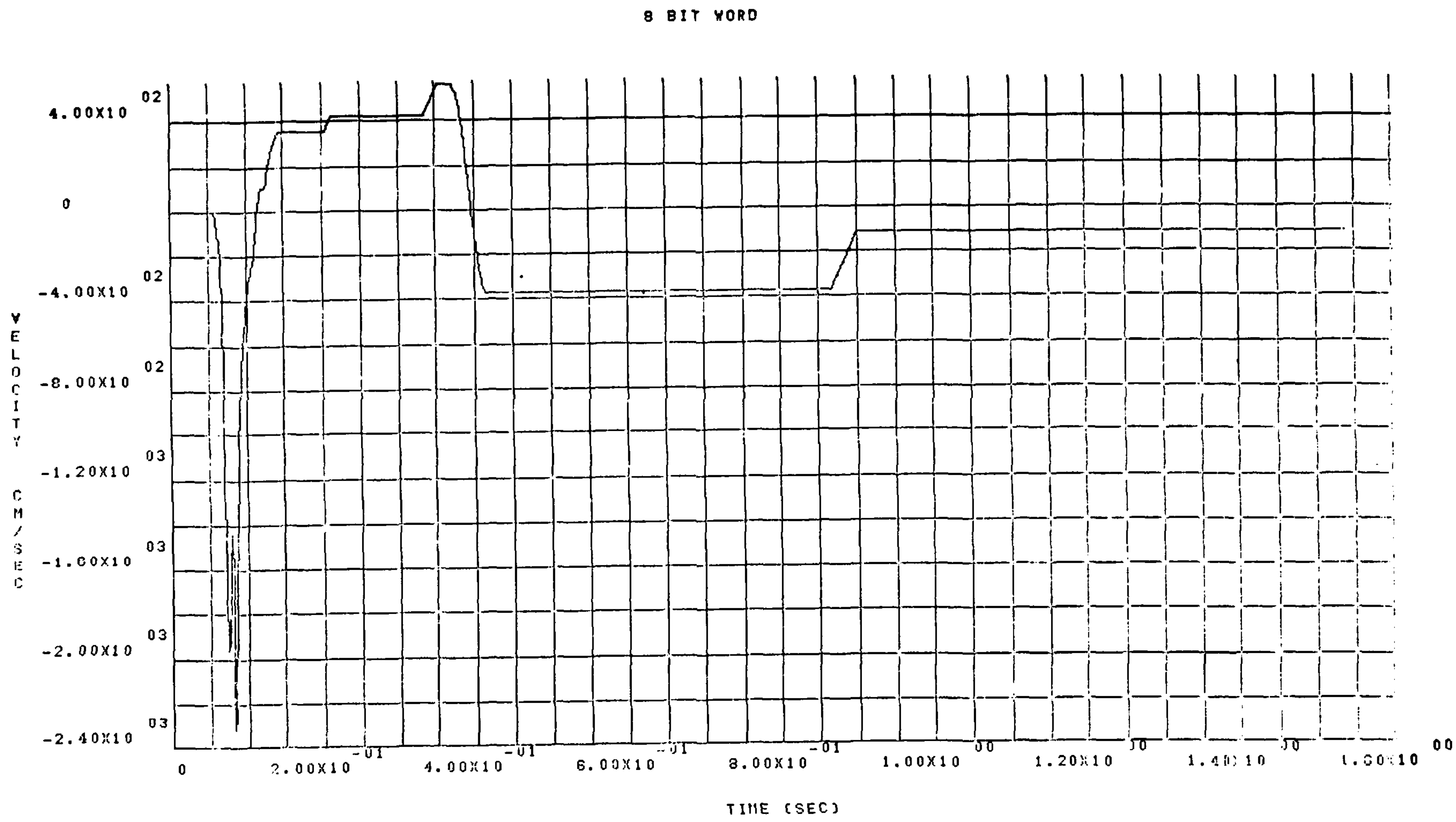

Figure 9. Velocity vs time.
8 significant bits word size.

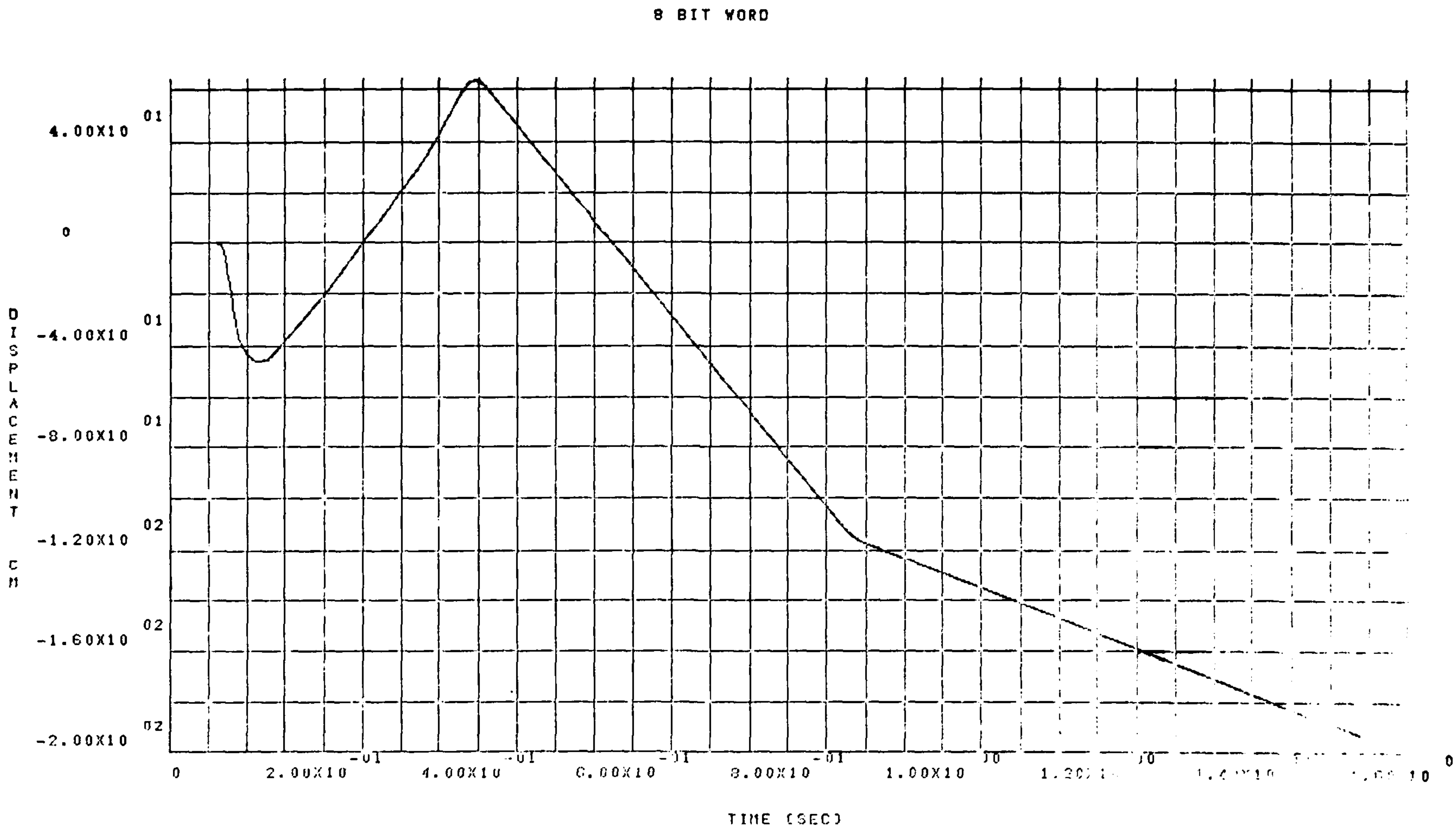

Figure 10. Displacement vs time.
8 significant bits word size.

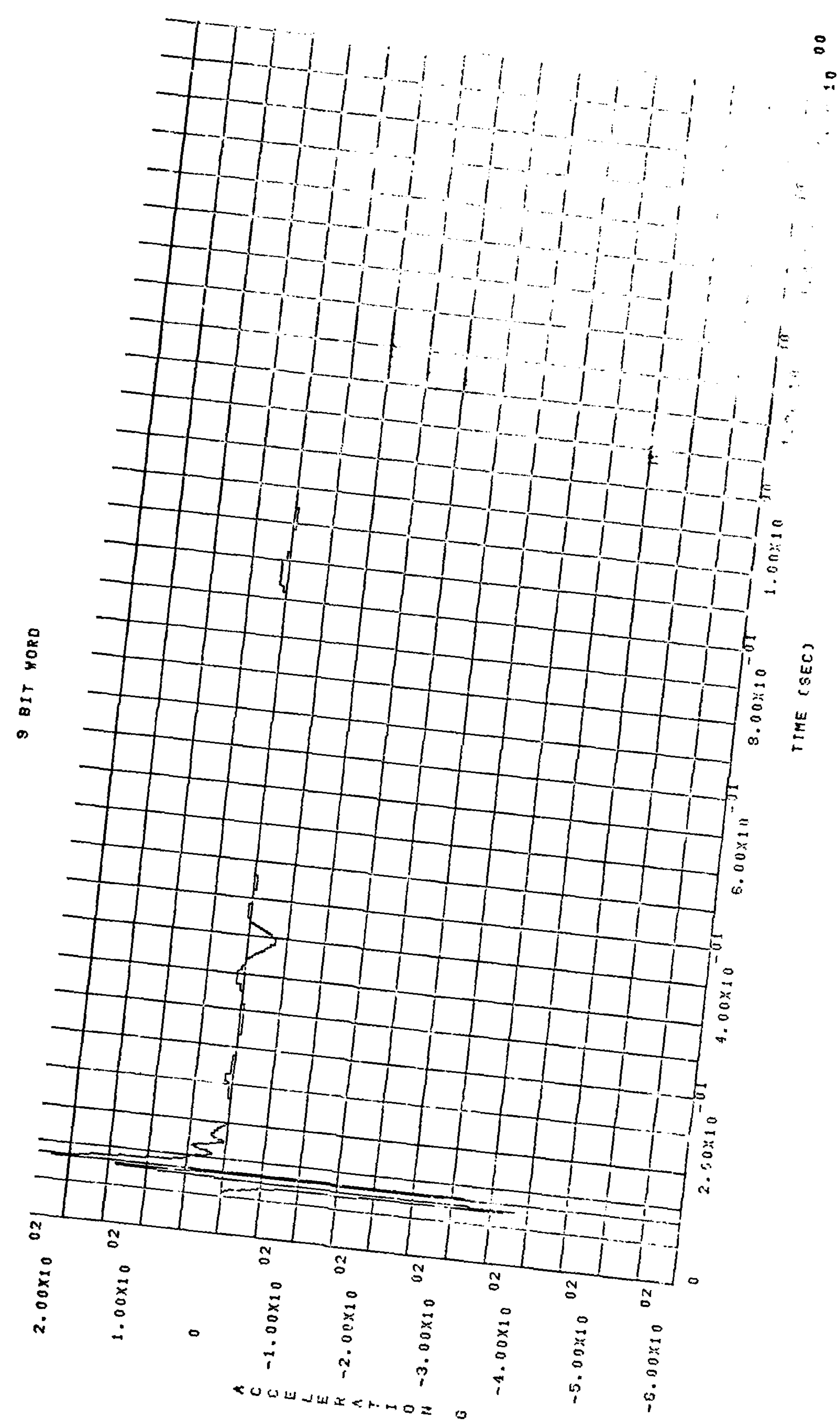

Figure 11. Acceleration vs time.
9 significant bits word size.

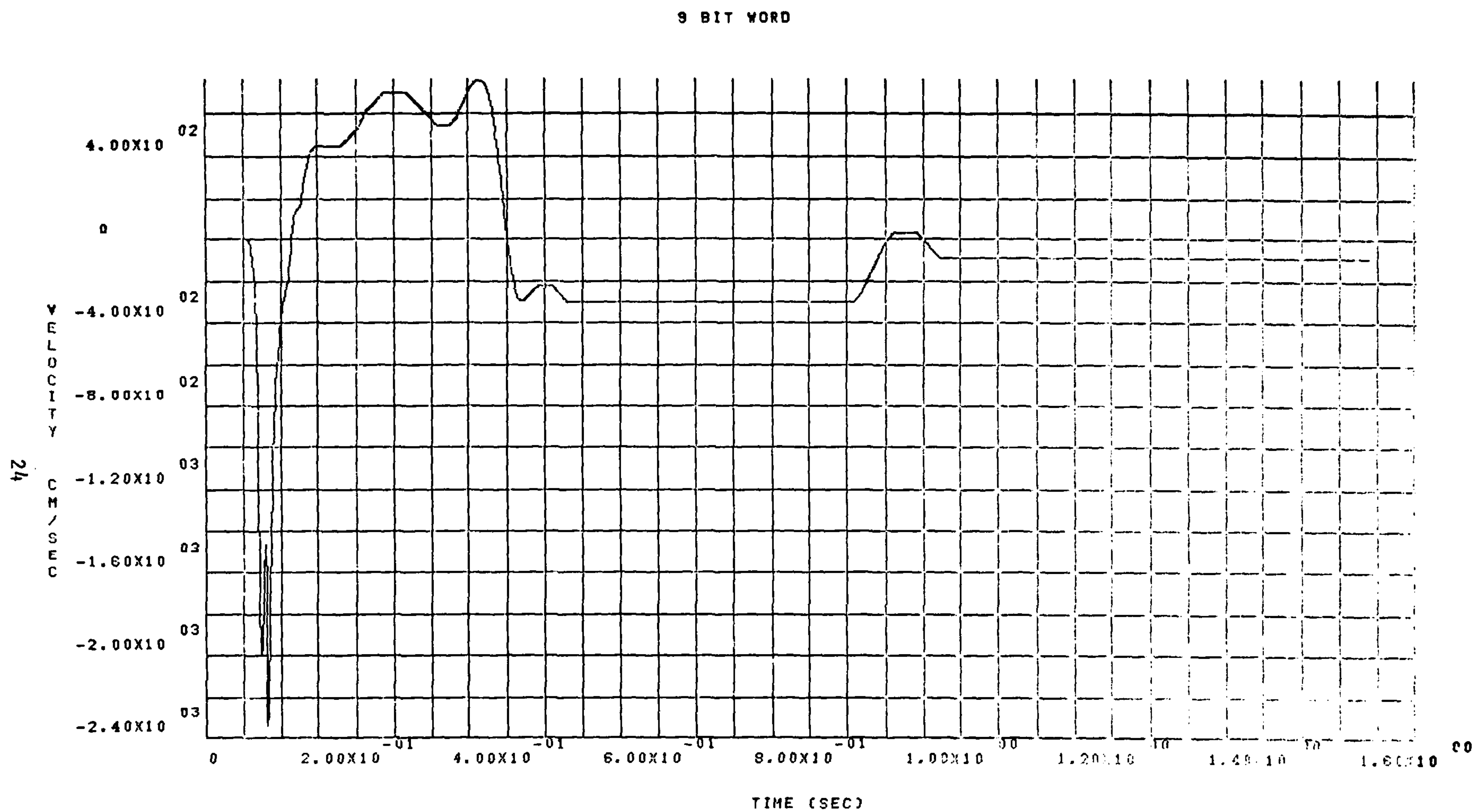

Figure 12. Velocity vs time.
9 significant bits word size.

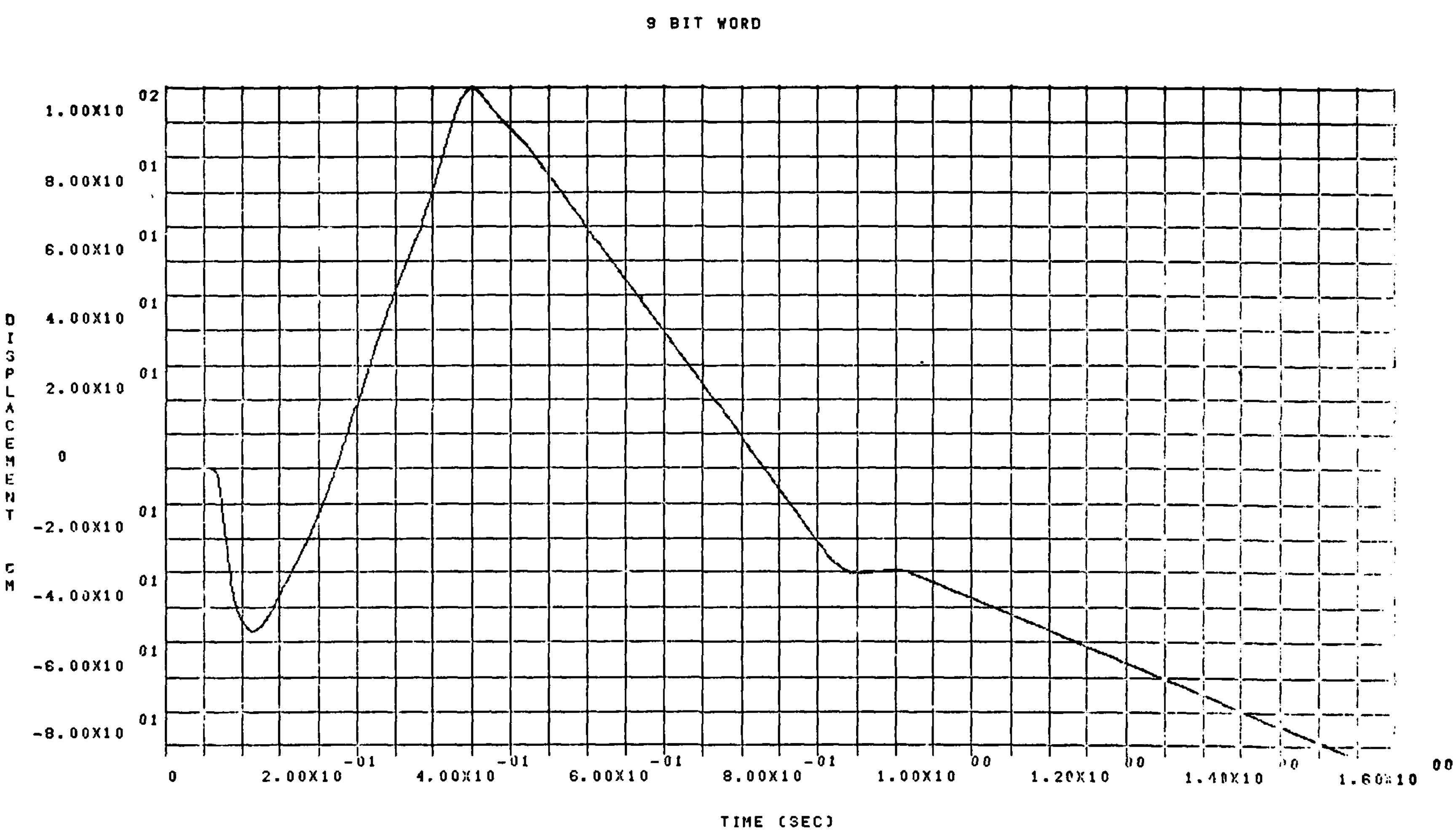

Figure 13. Displacement vs time.
9 significant bits word size.

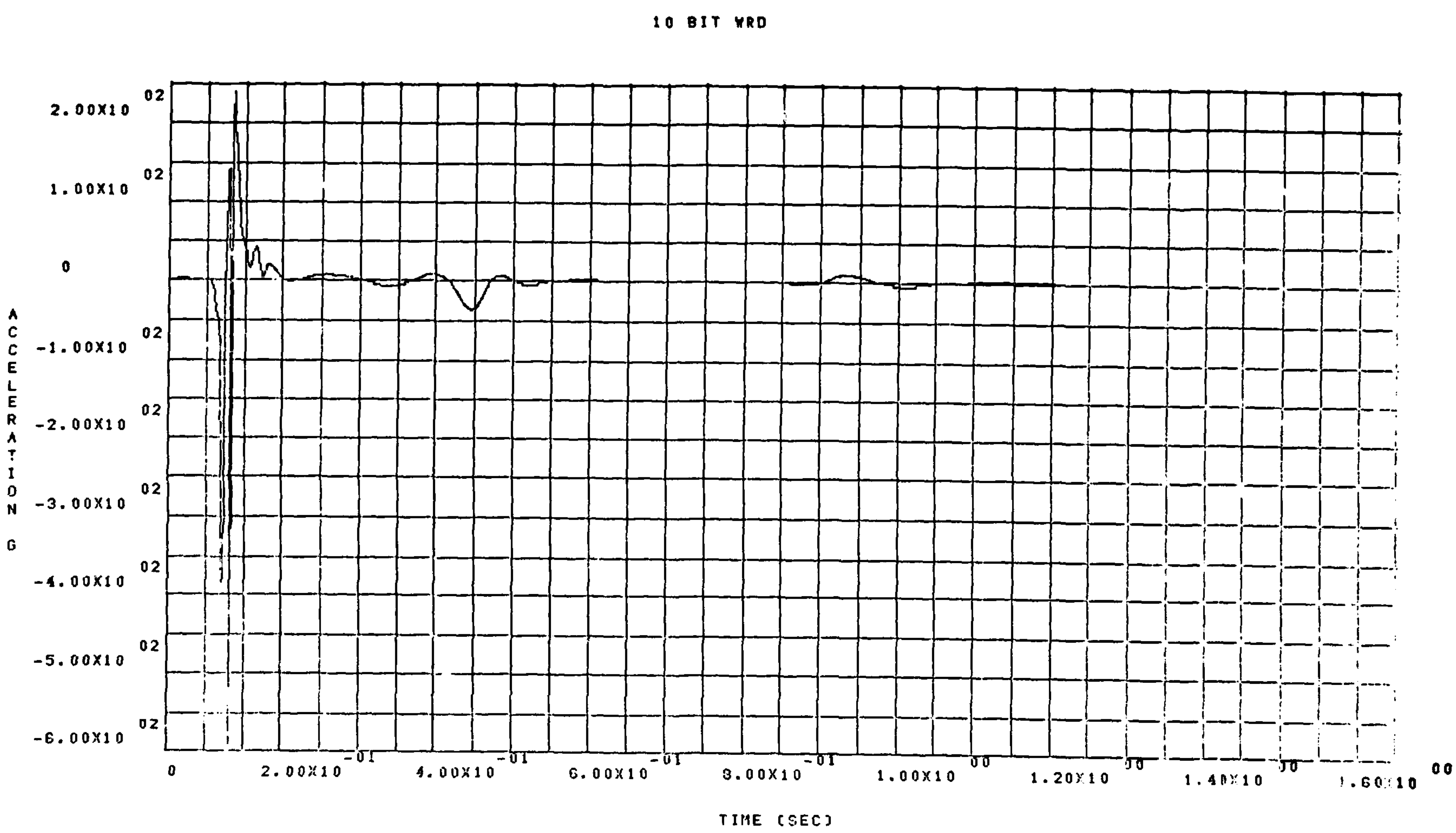

Figure 14. Acceleration vs time.
10 significant bits word size.

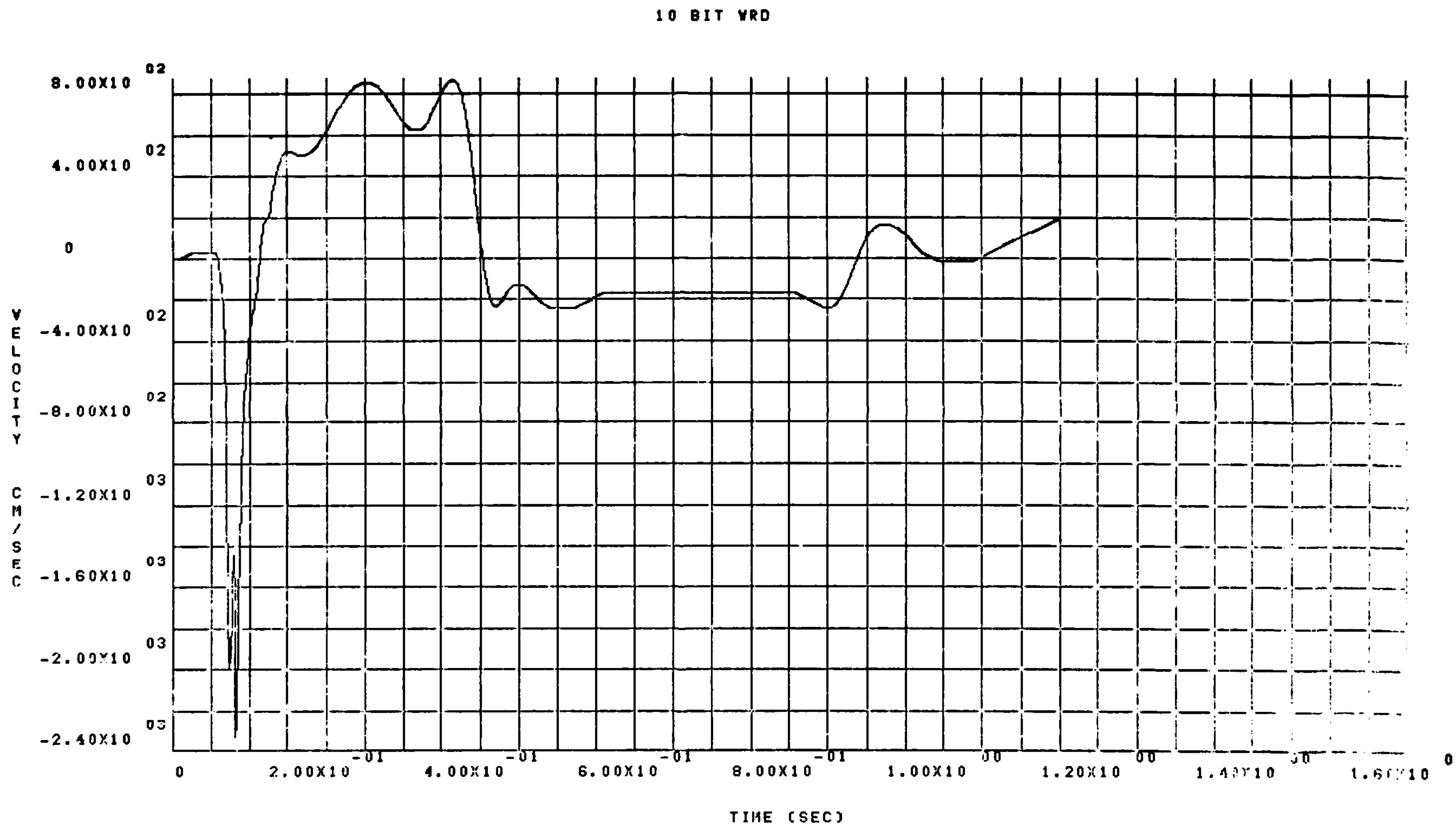

Figure 15. Velocity vs time.
10 significant bits word size.

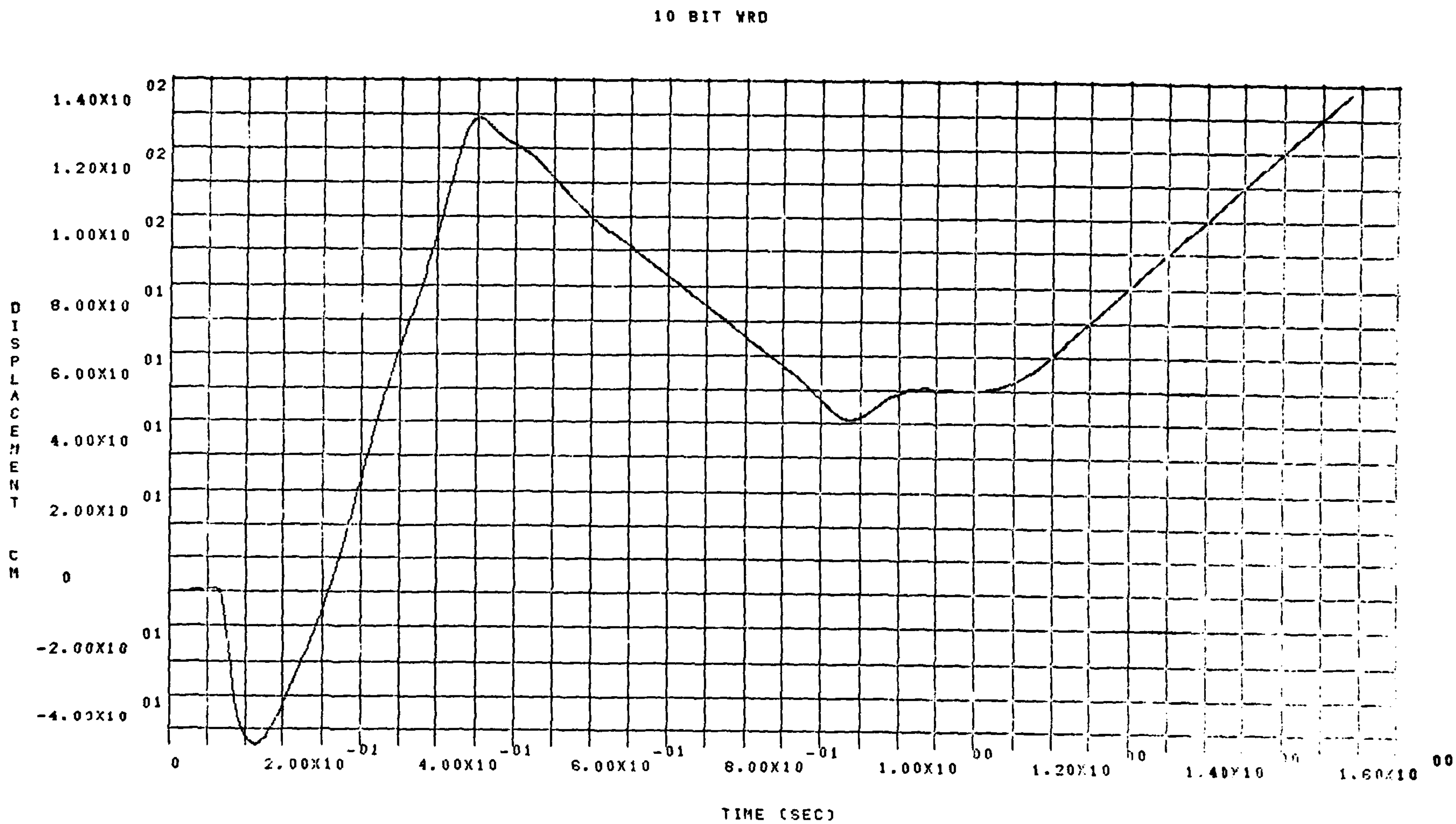

Figure 16. Displacement vs time.
10 significant bits word size.

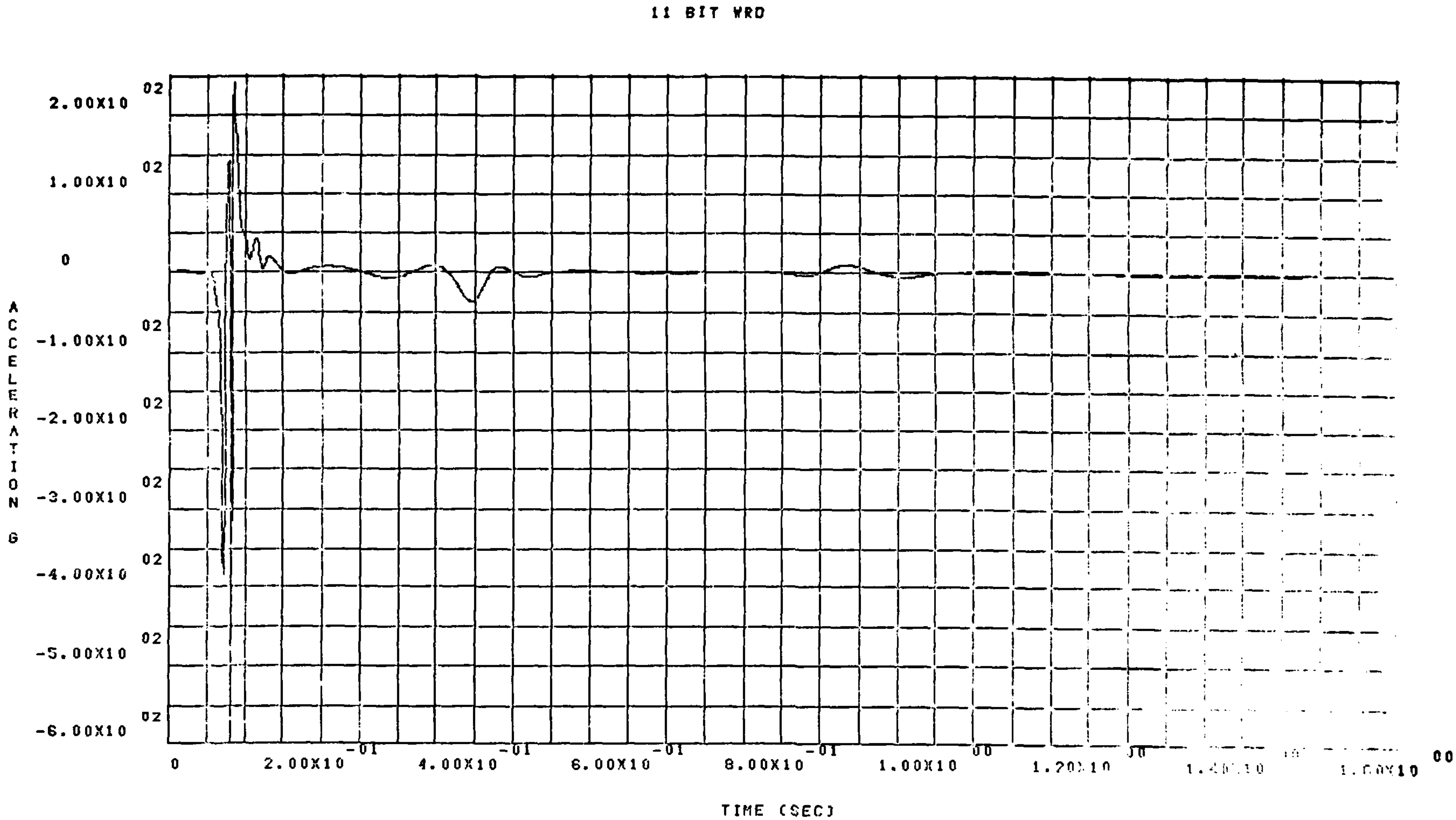

Figure 17. Acceleration vs time.
11 significant bits word size.

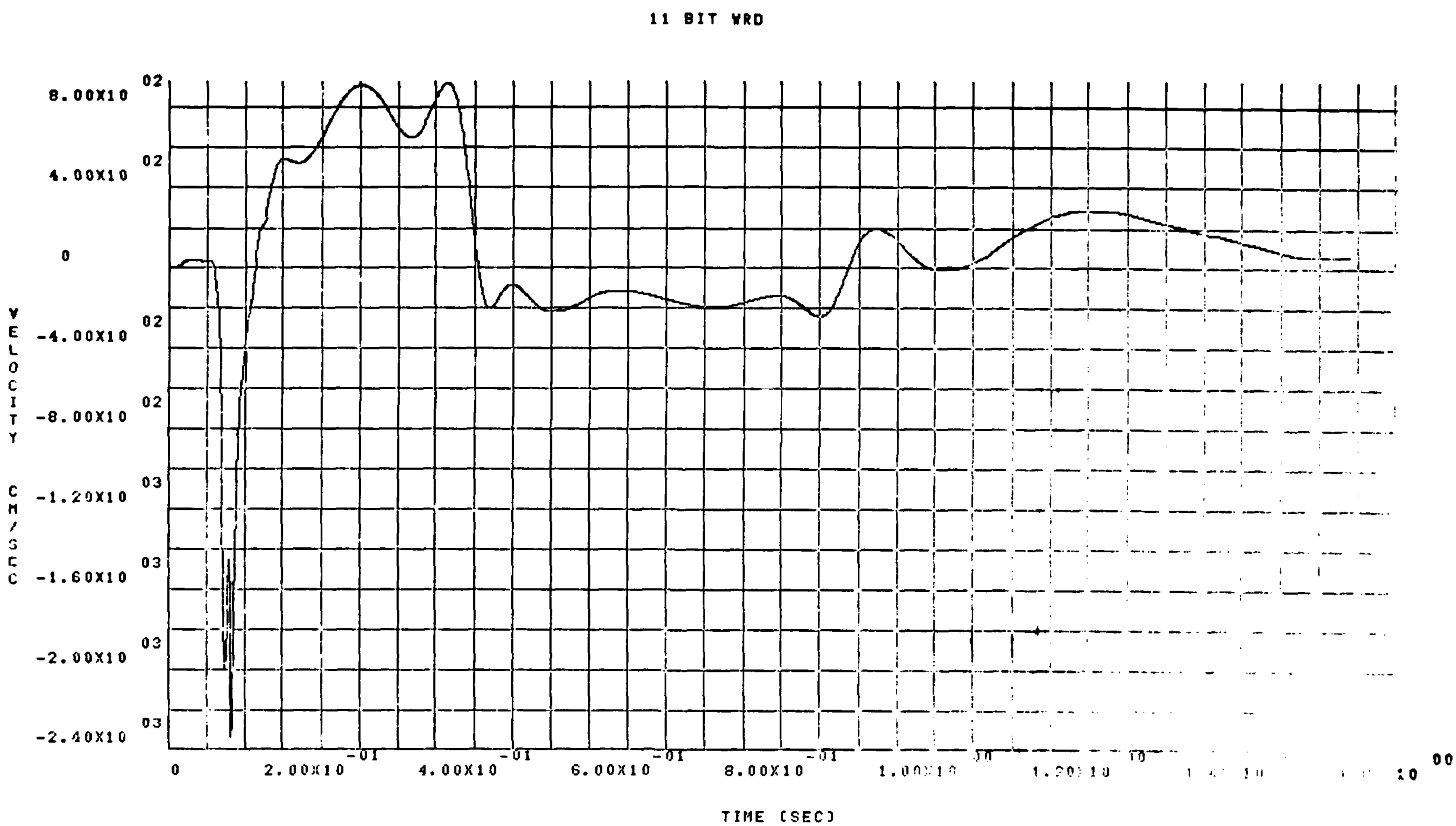

Figure 18. Velocity vs time.
11 significant bits word size.

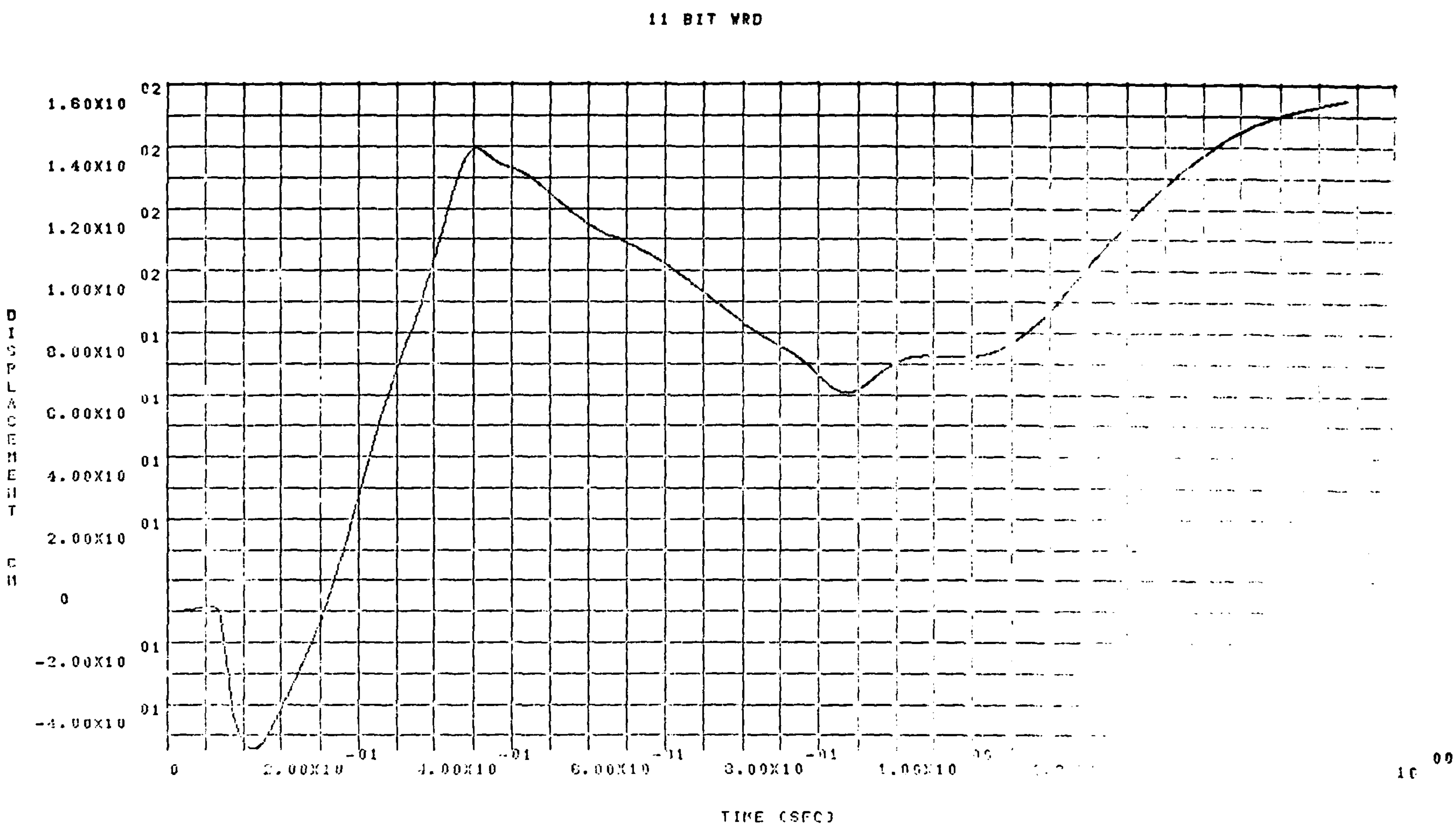

Figure 19. Displacement vs time.
11 significant bits word size.

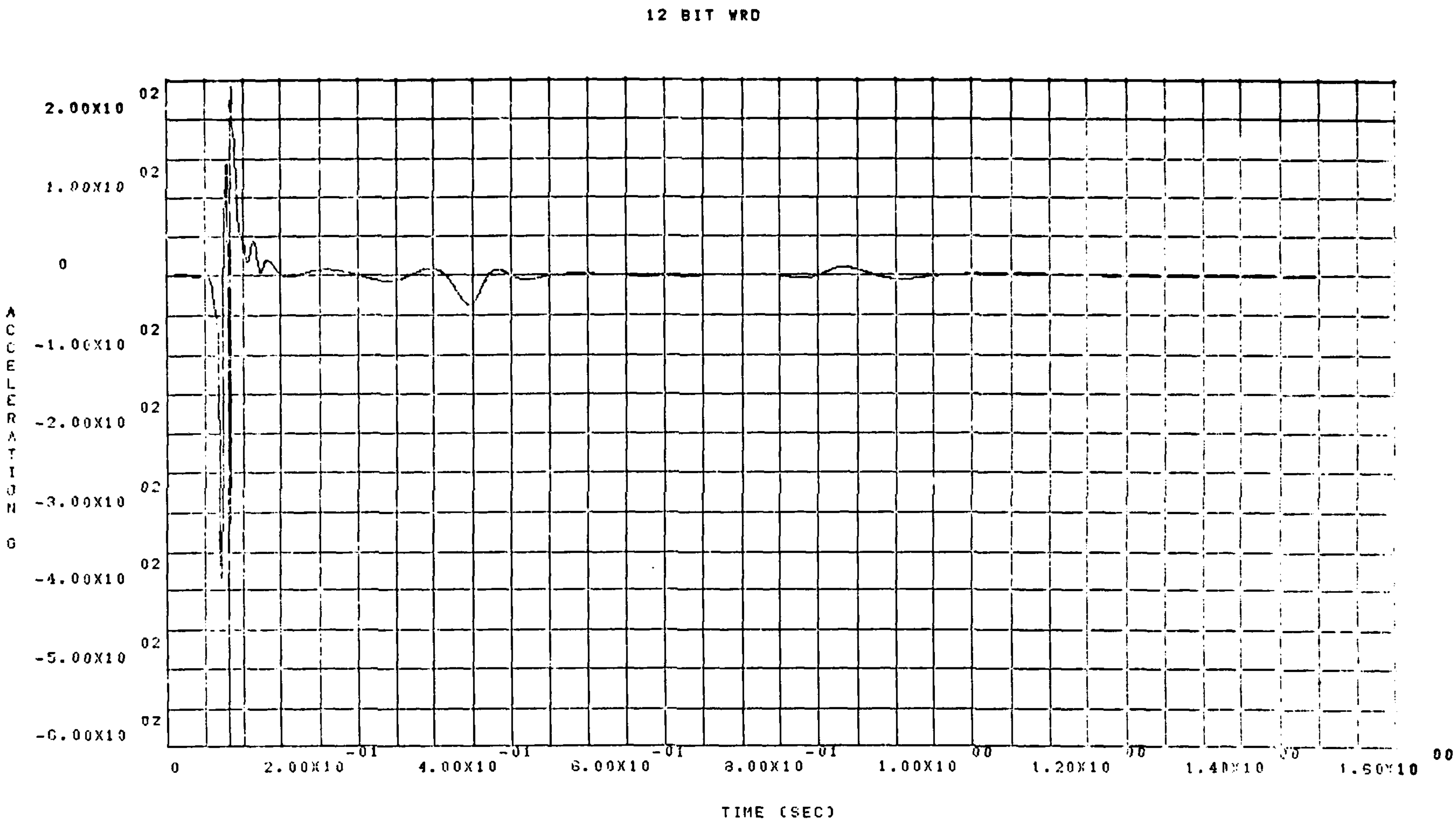

Figure 20. Acceleration vs time.
12 significant bits word size.

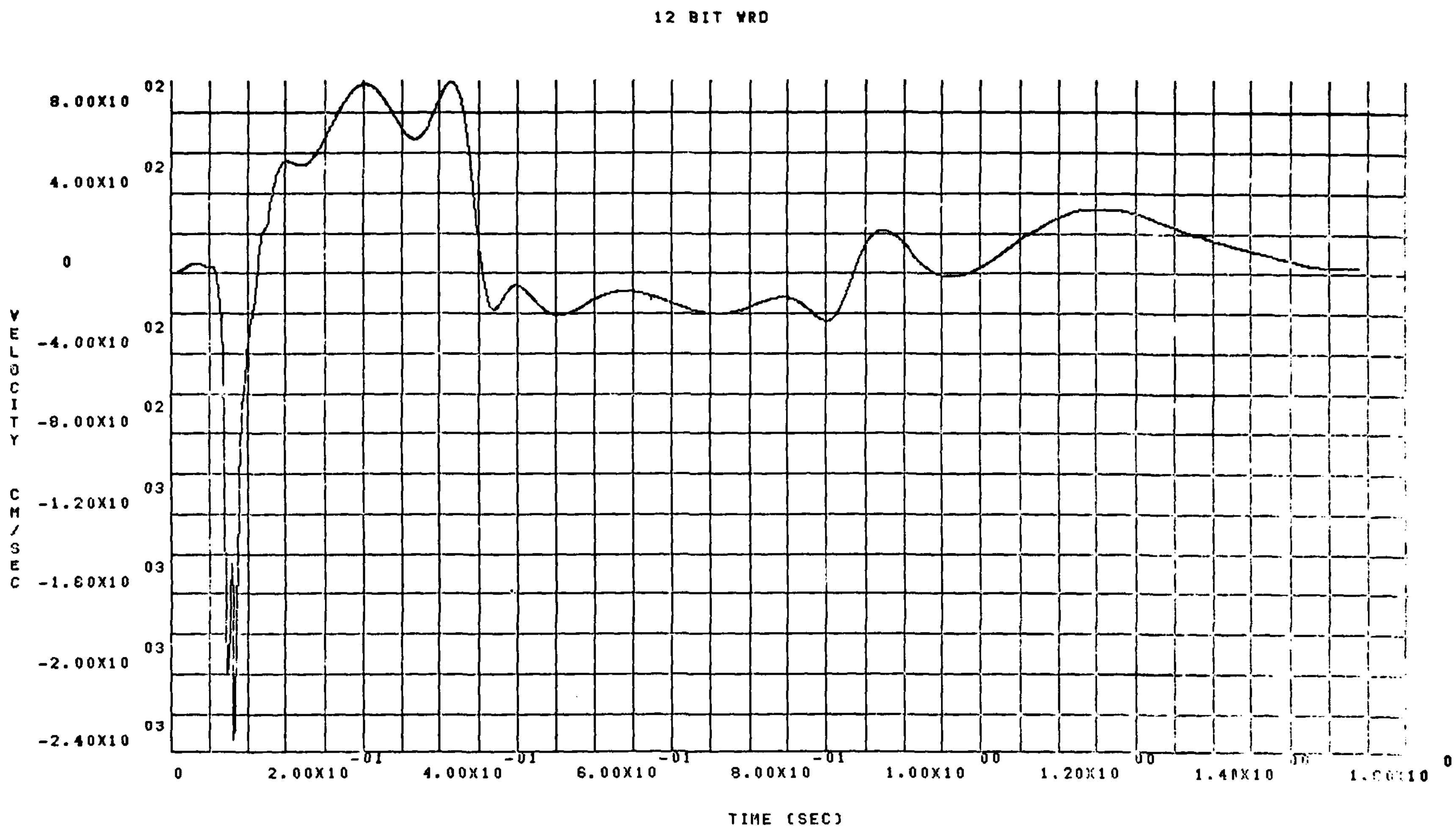

Figure 21. Velocity vs time.
12 significant bits word size.

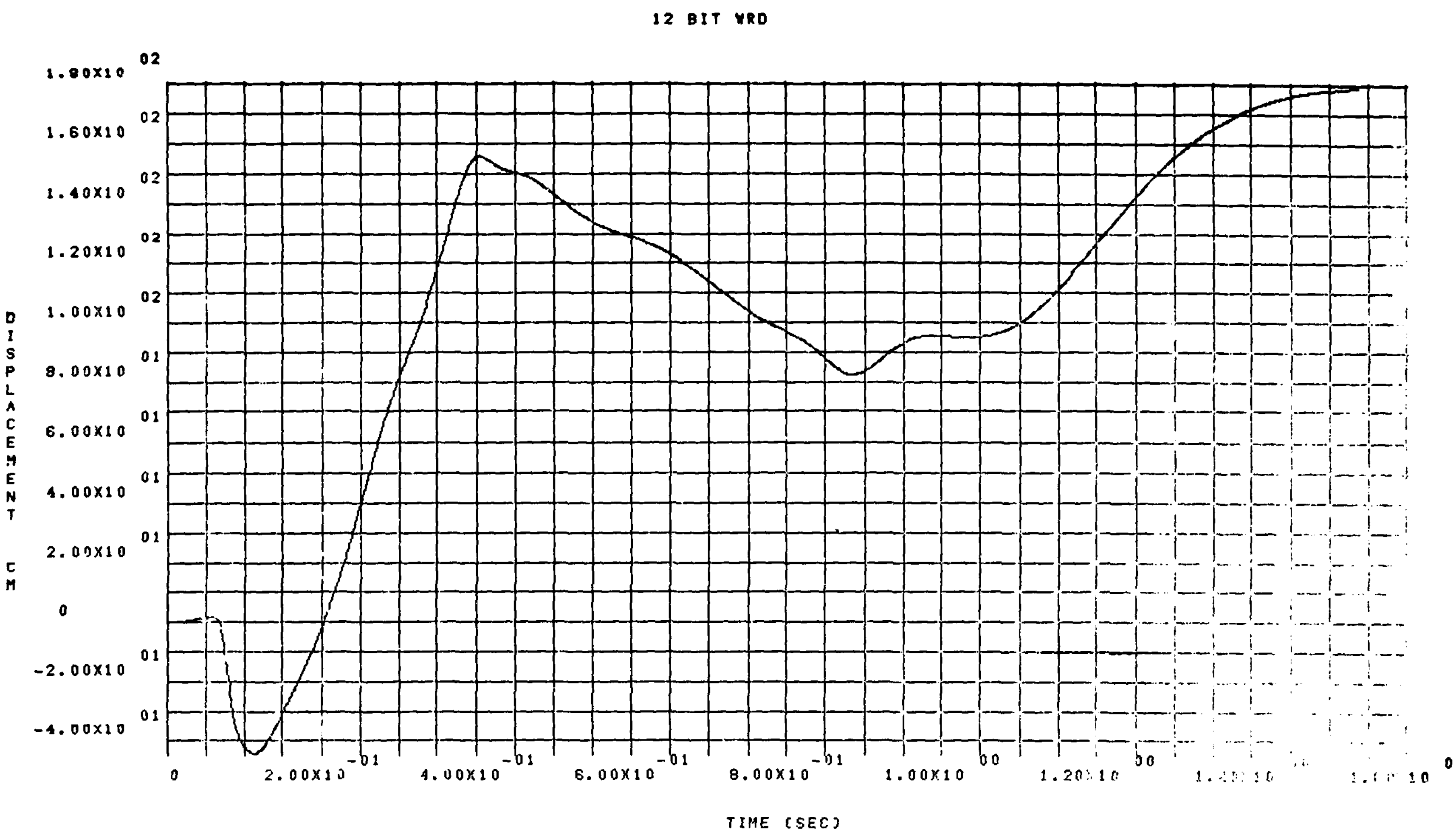

Figure 22. Displacement vs time.
12 significant bits word size.

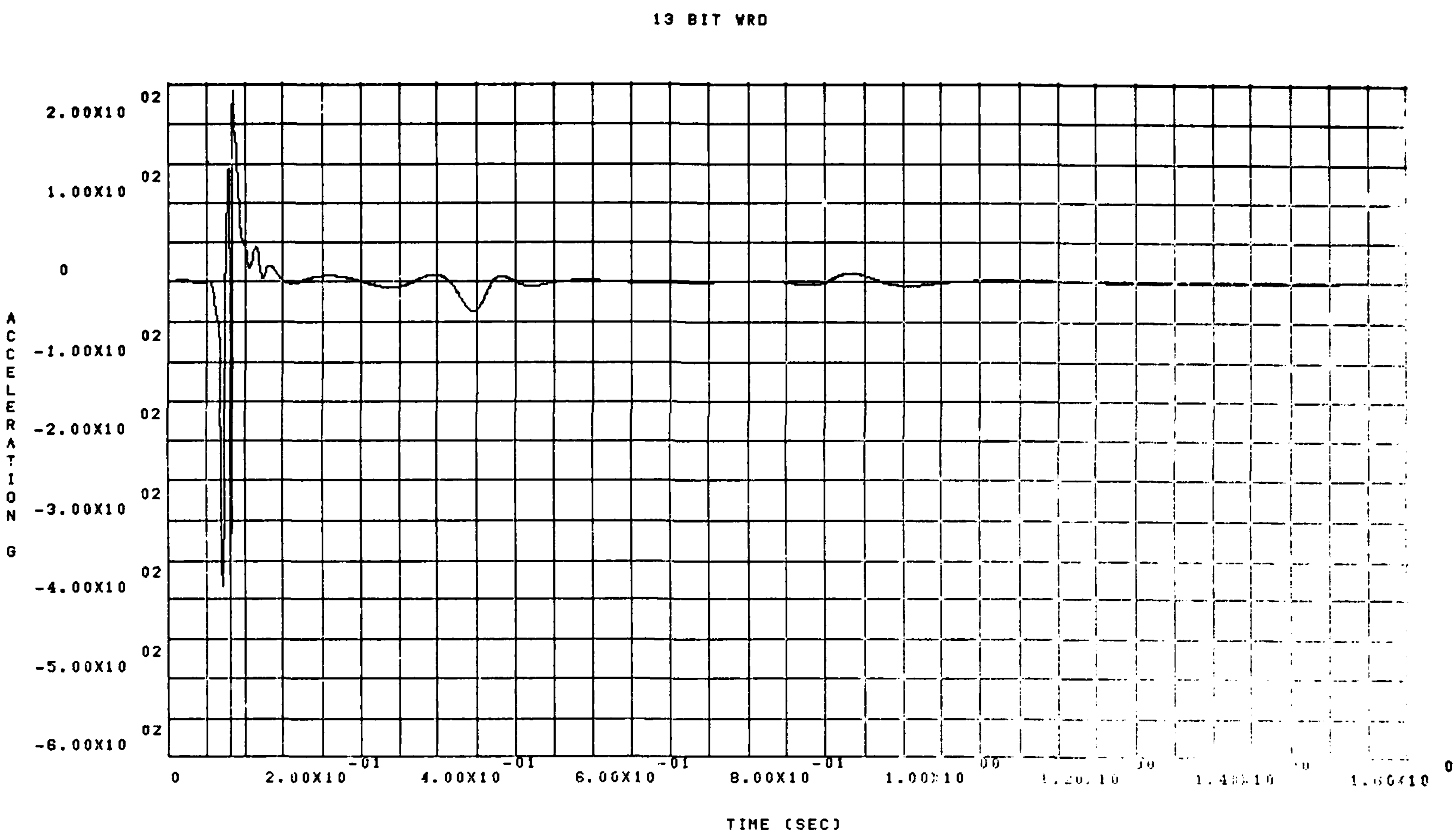

Figure 23. Acceleration vs time.
13 significant bits word size.

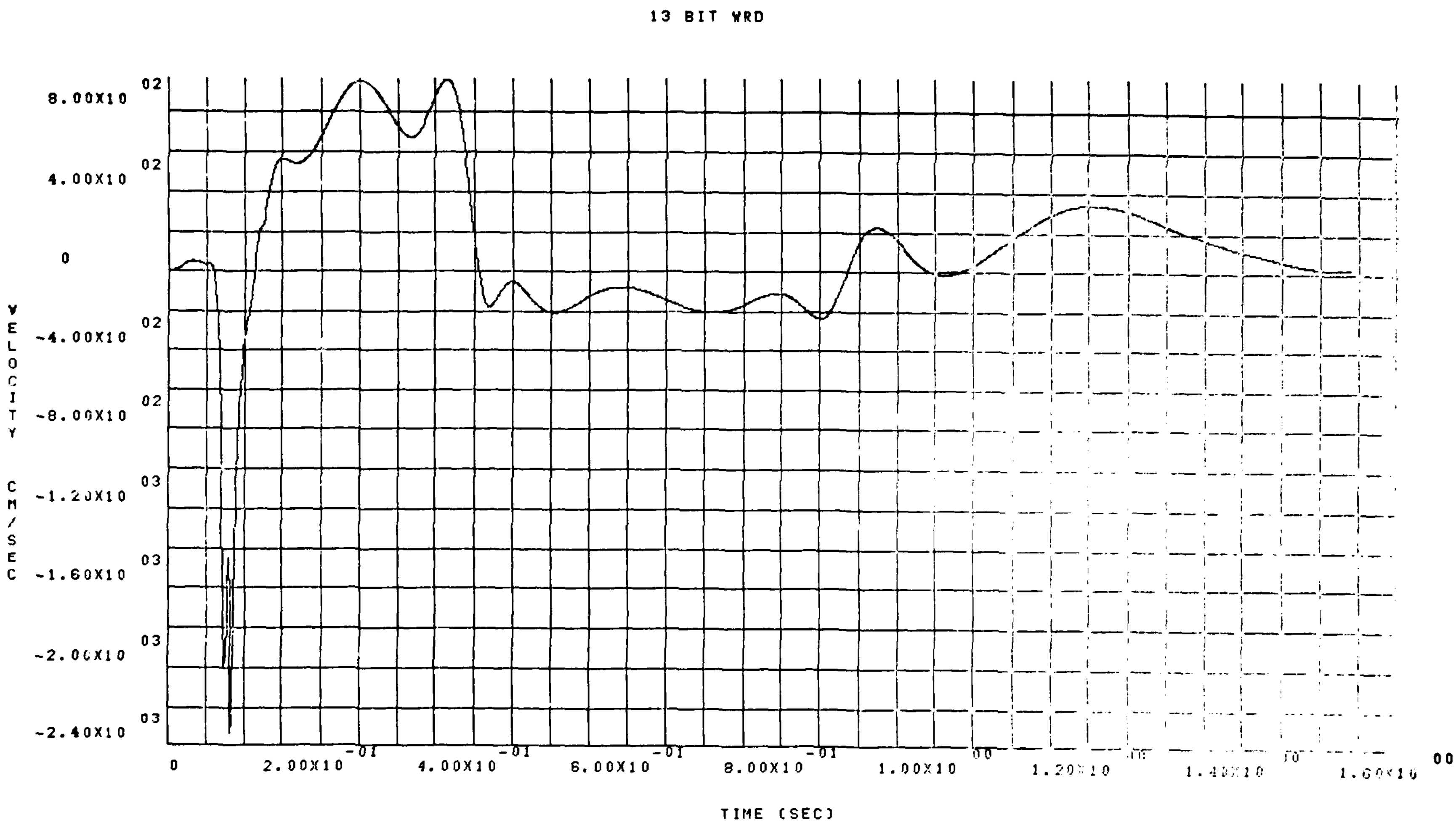

Figure 24. Velocity vs time.
13 significant bits word size.

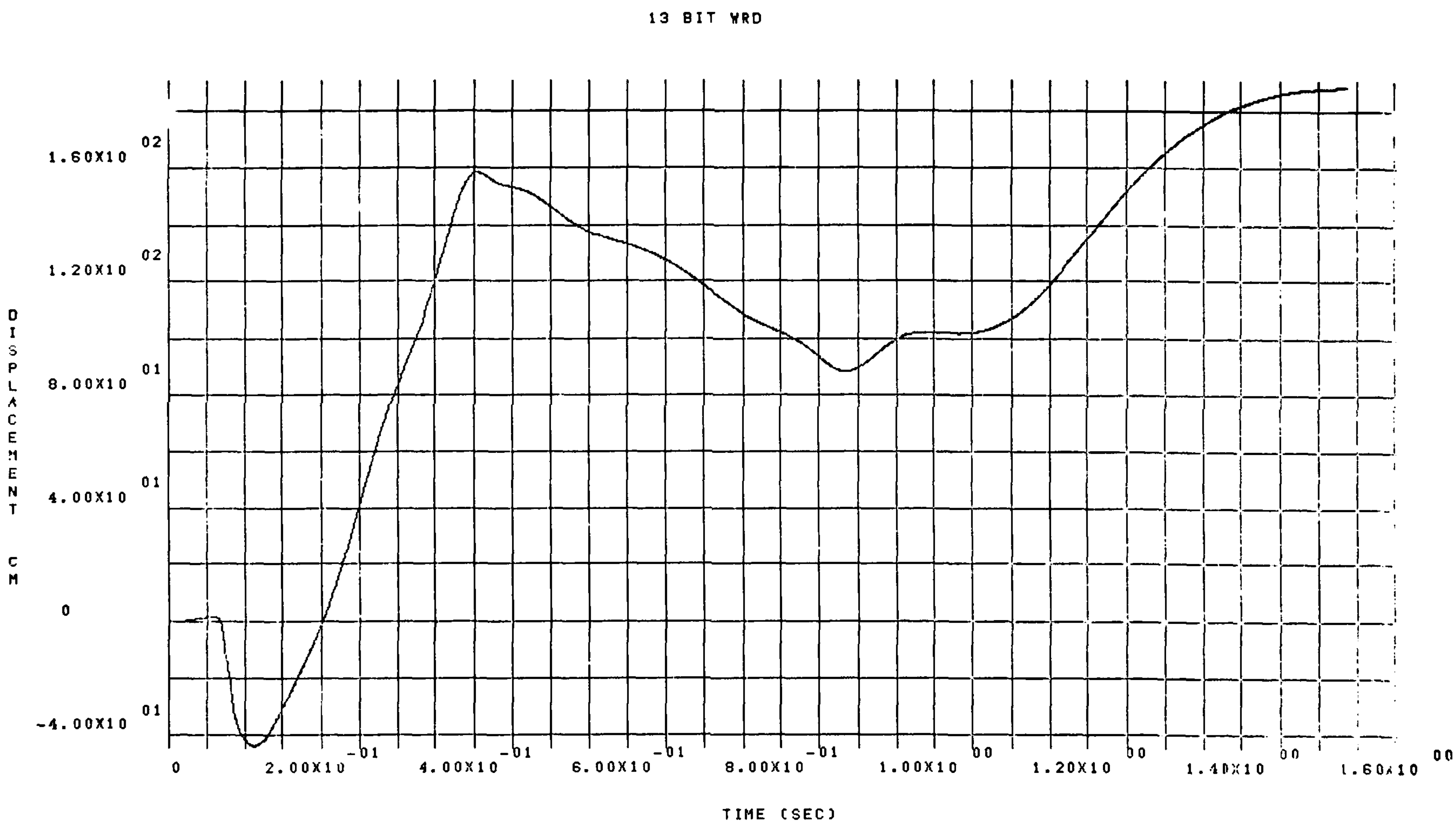

Figure 25. Displacement vs time.
13 significant bits word size.

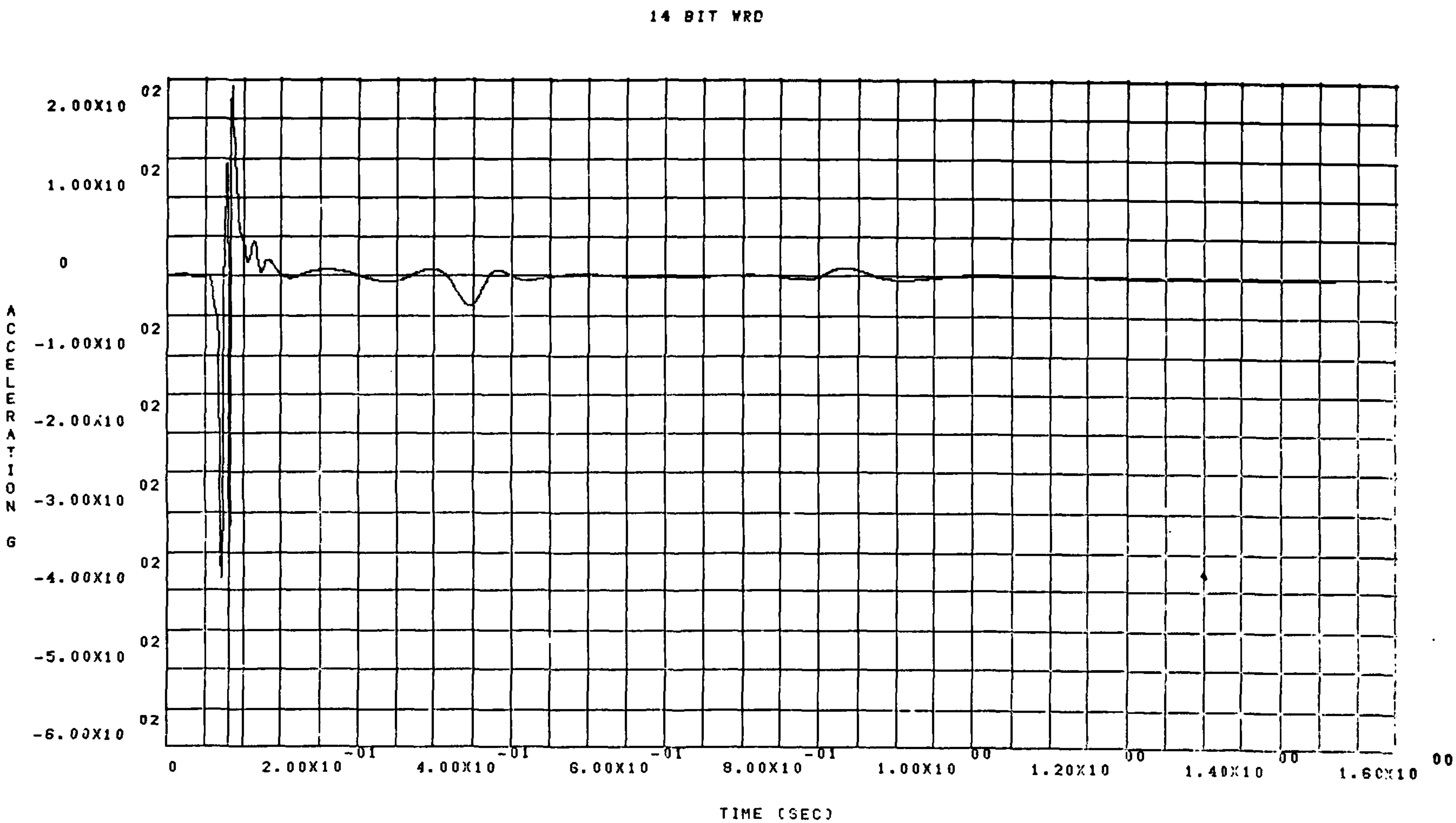

Figure 26. Acceleration vs time.
14 significant bits word size.

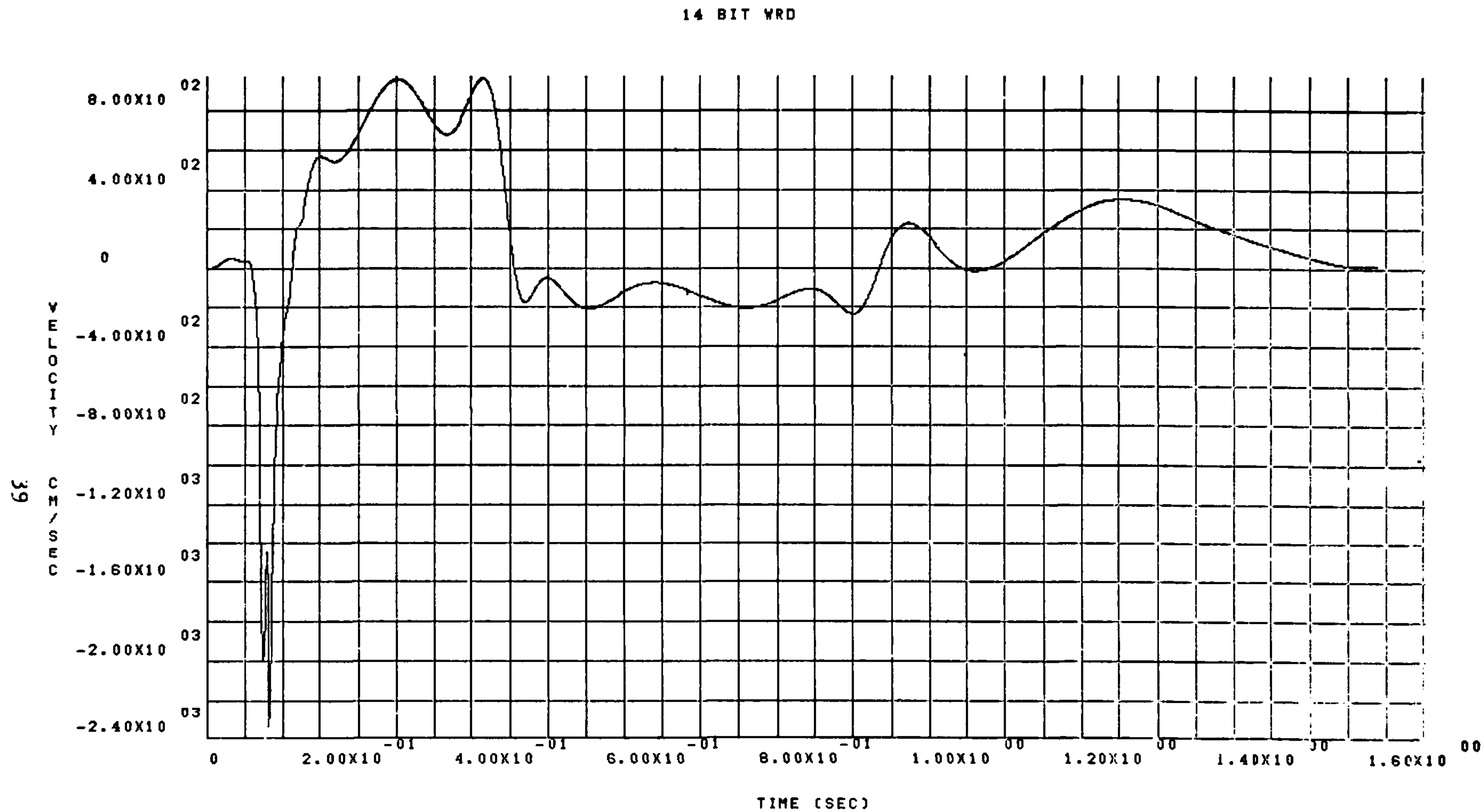

Figure 27. Velocity vs time.
14 significant bits word size.

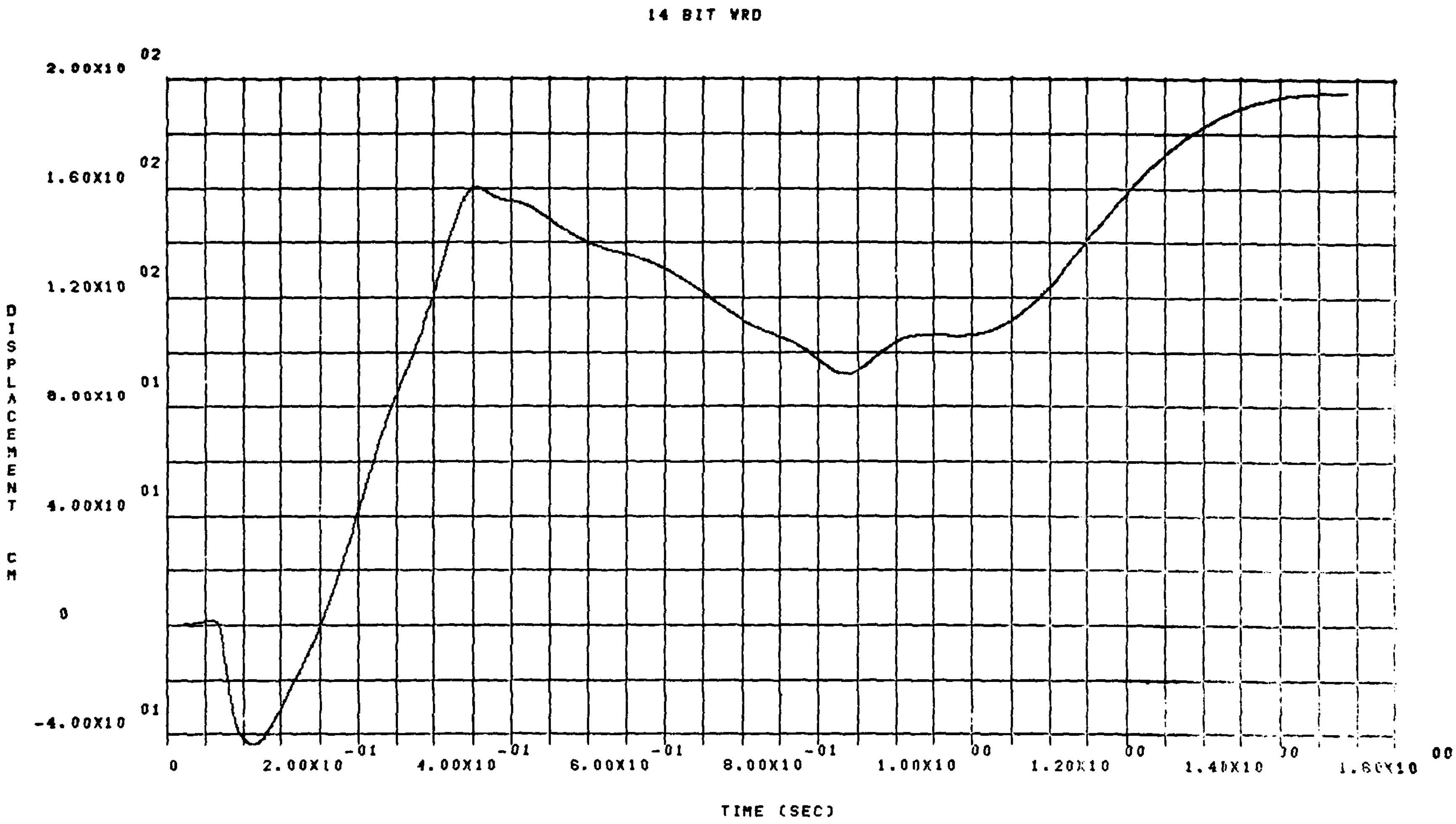

Figure 28. Displacement vs time.
14 significant bits word size.

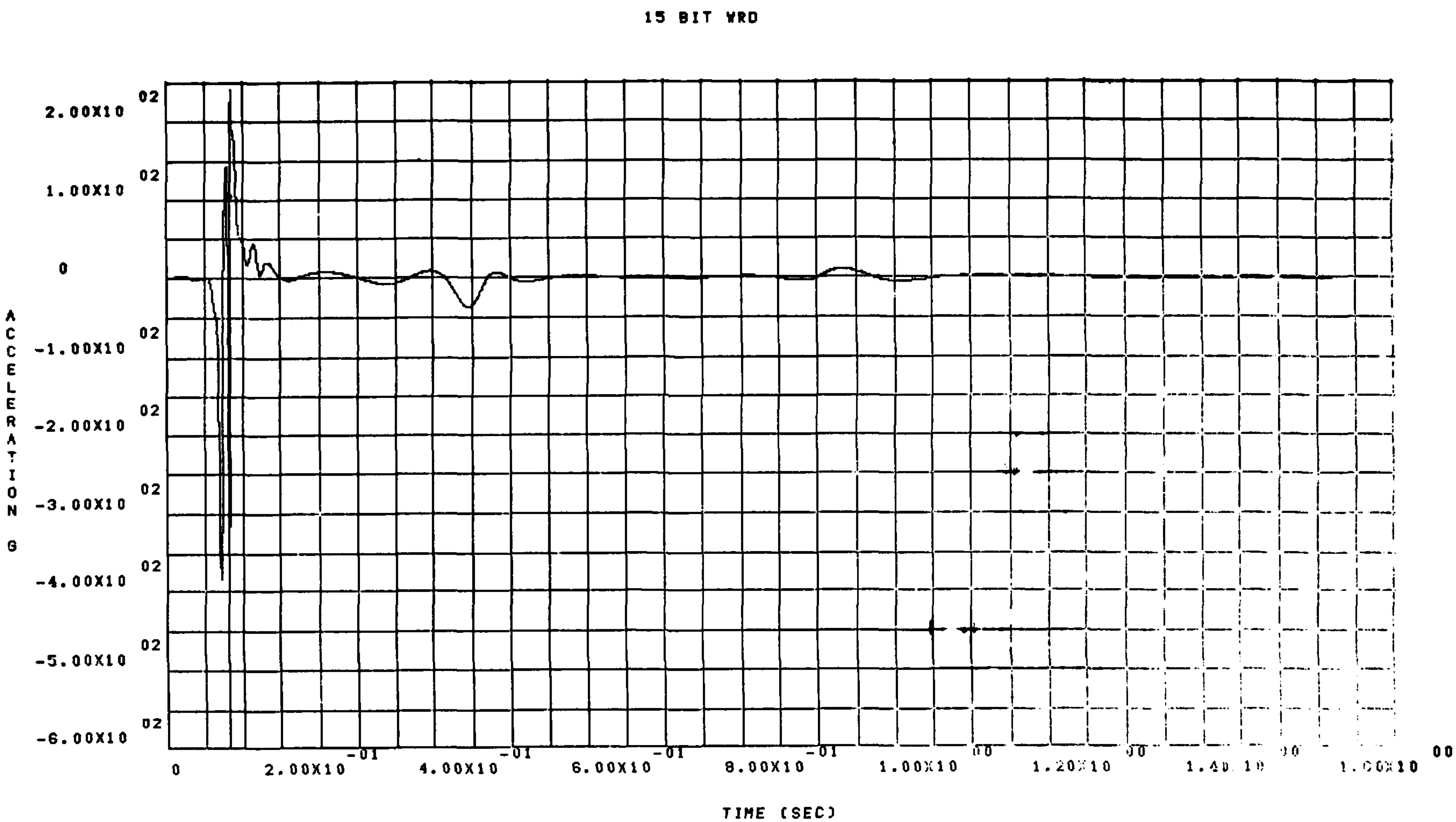

Figure 29. Acceleration vs time.
15 significant bits word size.

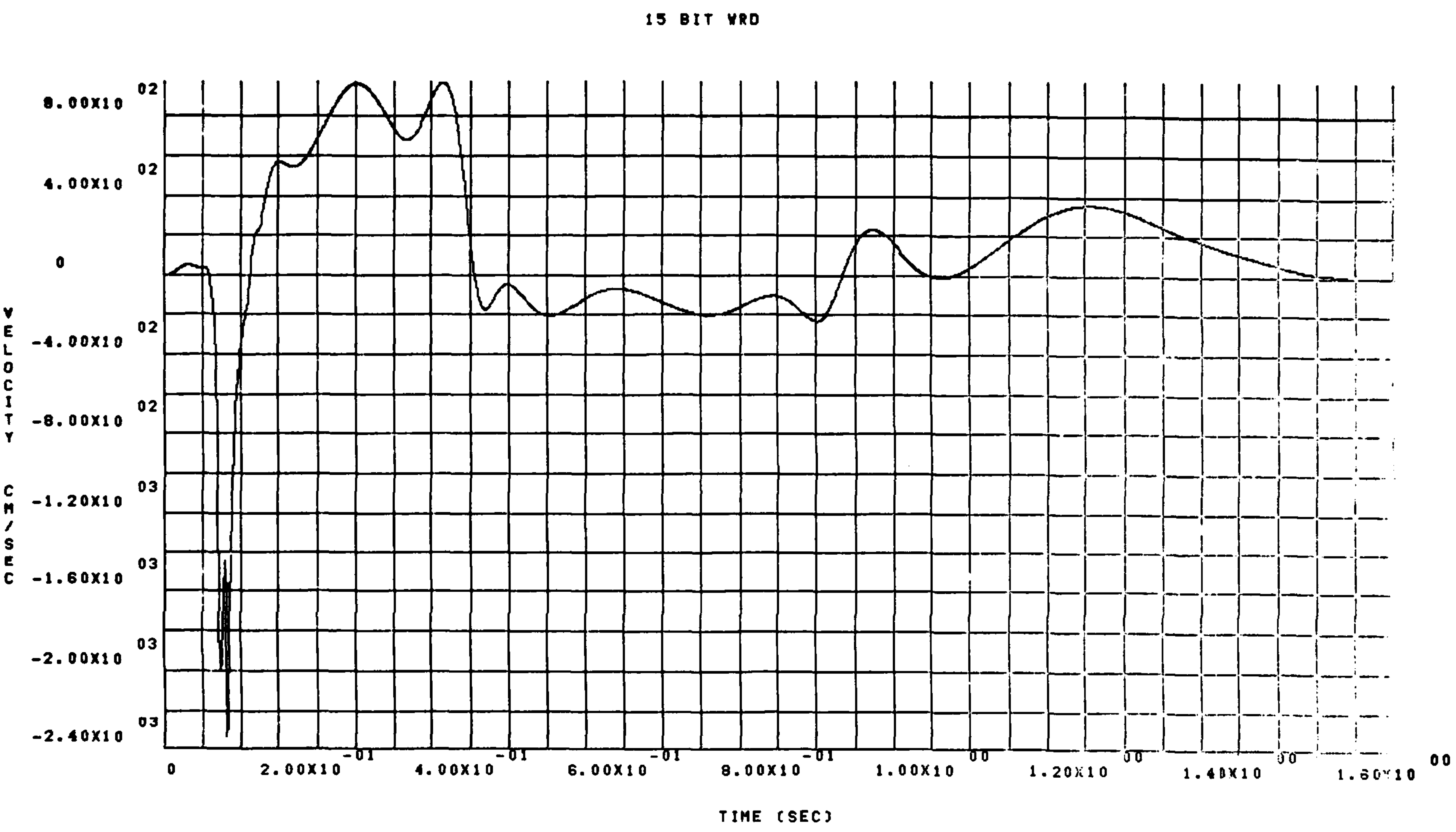

Figure 30. Velocity vs time.
15 significant bits word size.

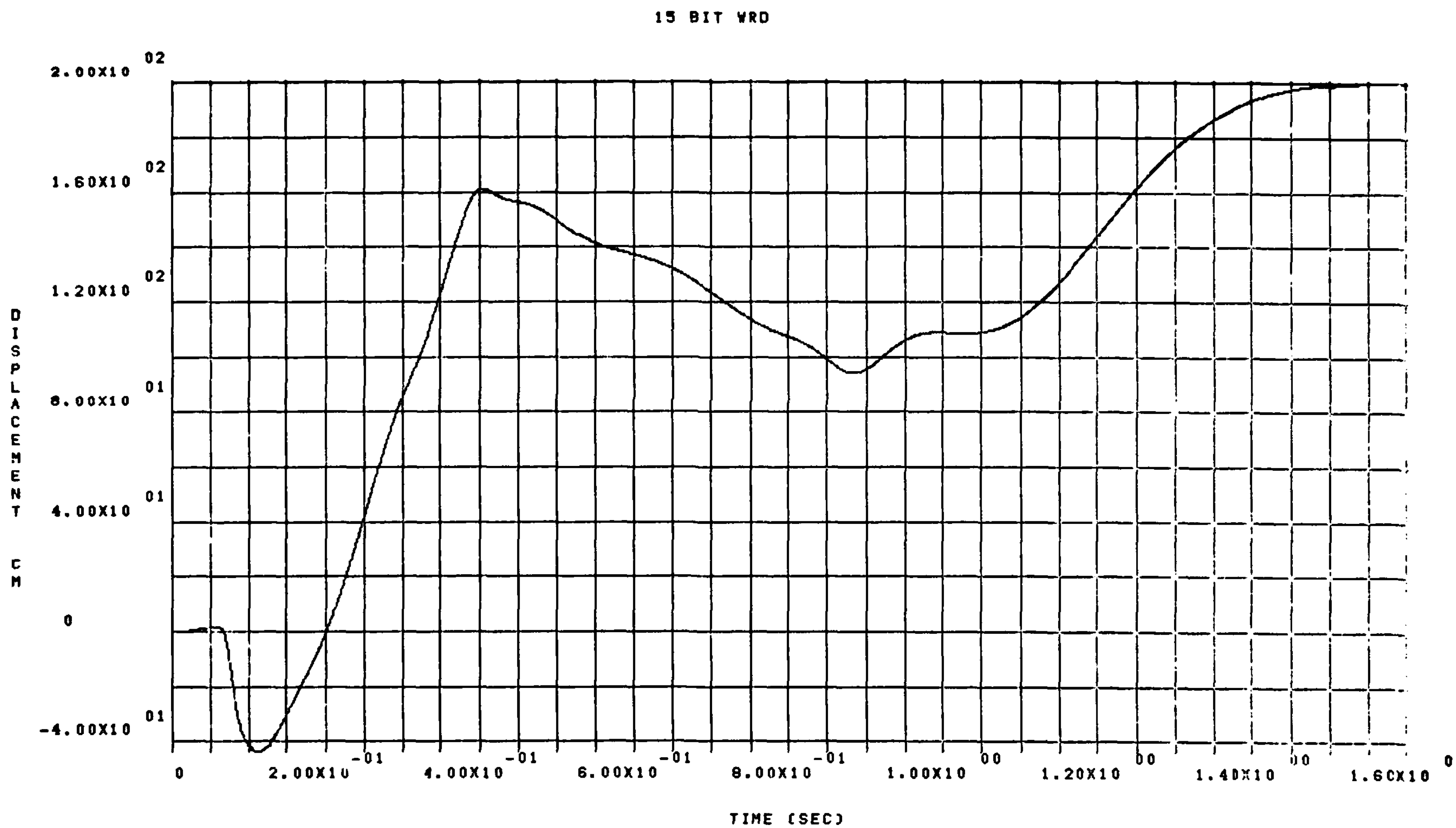

Figure 31. Displacement vs time.
15 significant bits word size.

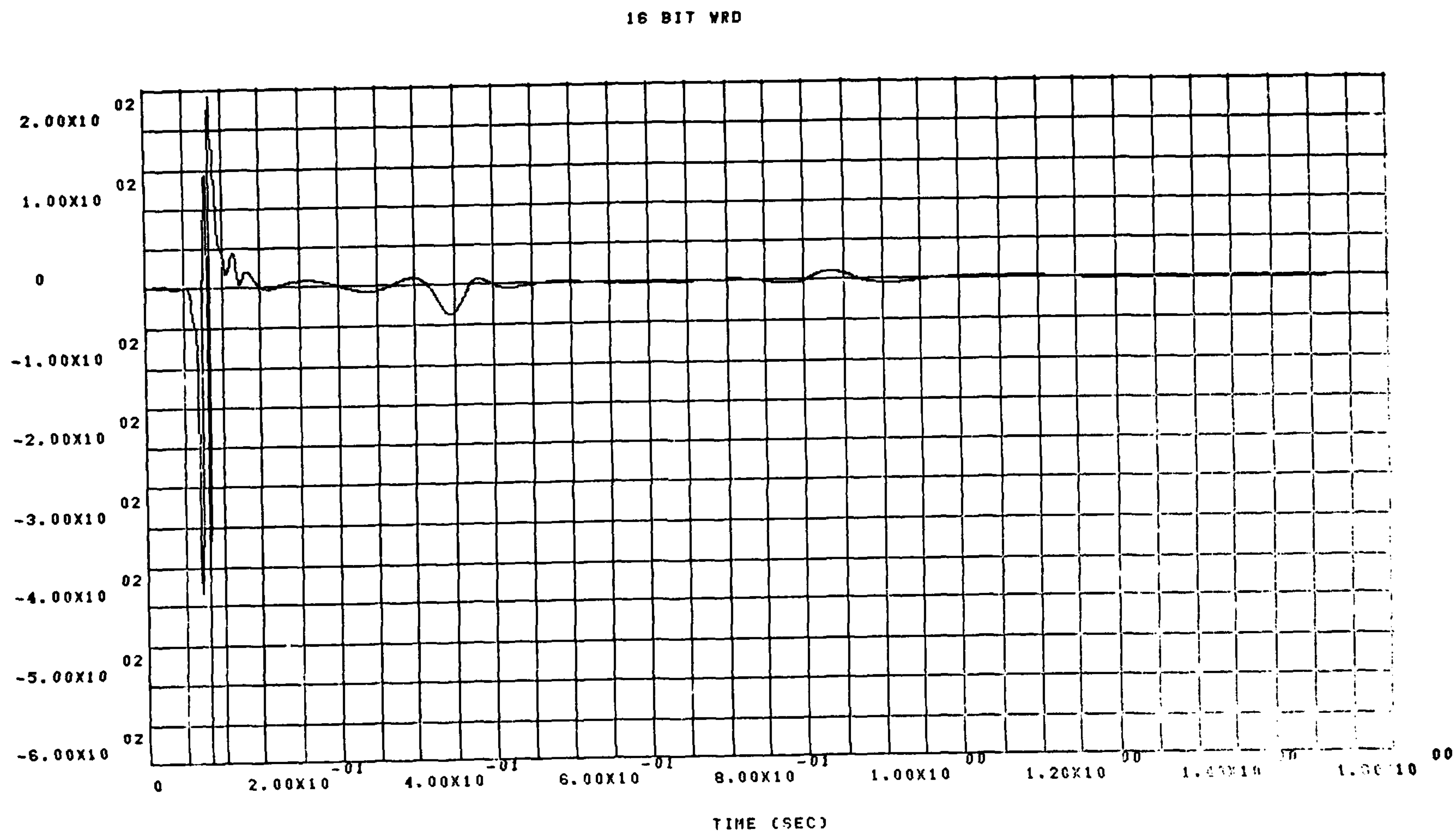

Figure 32. Acceleration vs time.
16 significant bits word size.

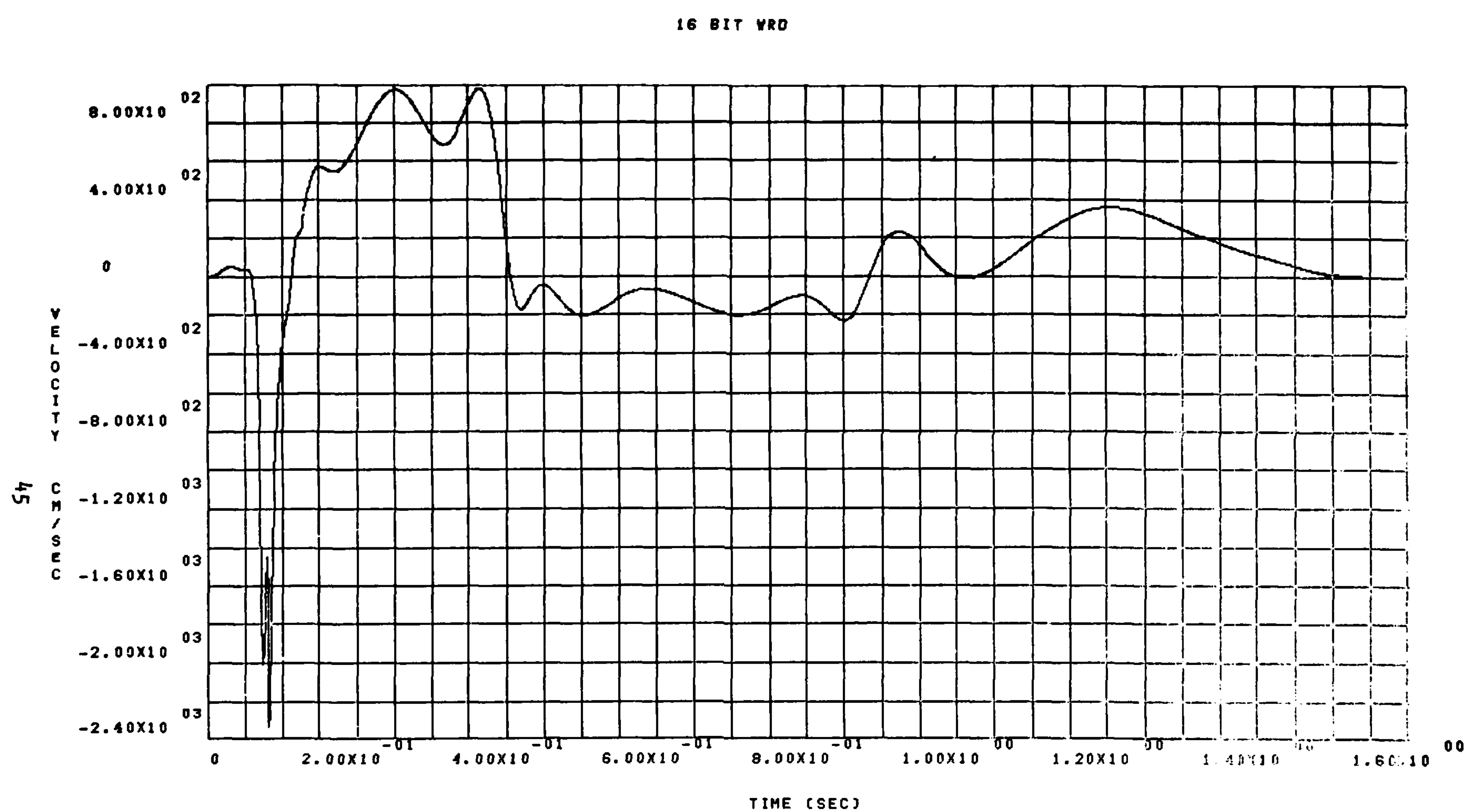

Figure 33. Velocity vs time.
16 significant bits word size.

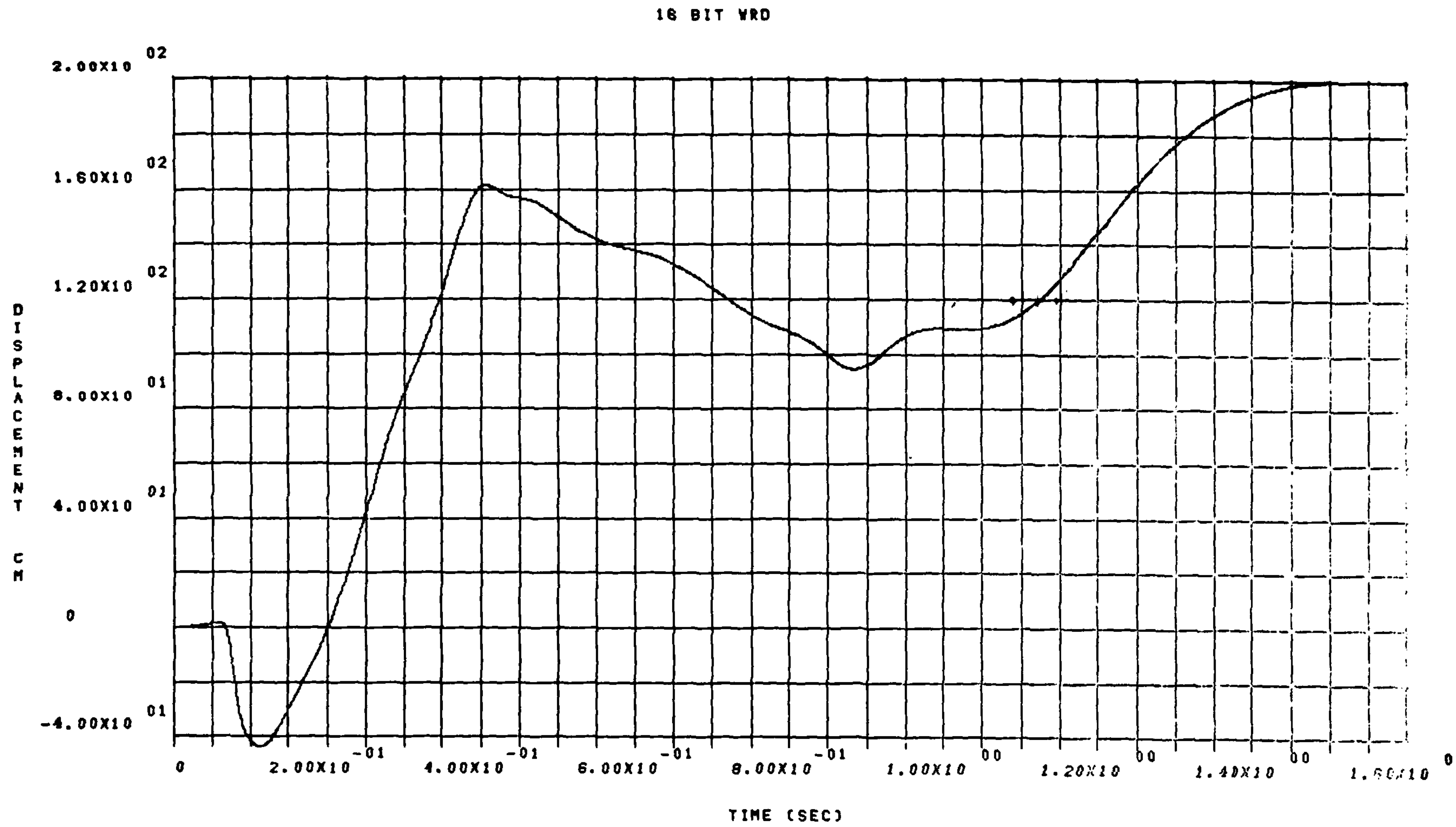

Figure 34. Displacement vs time.
16 significant bits word size.

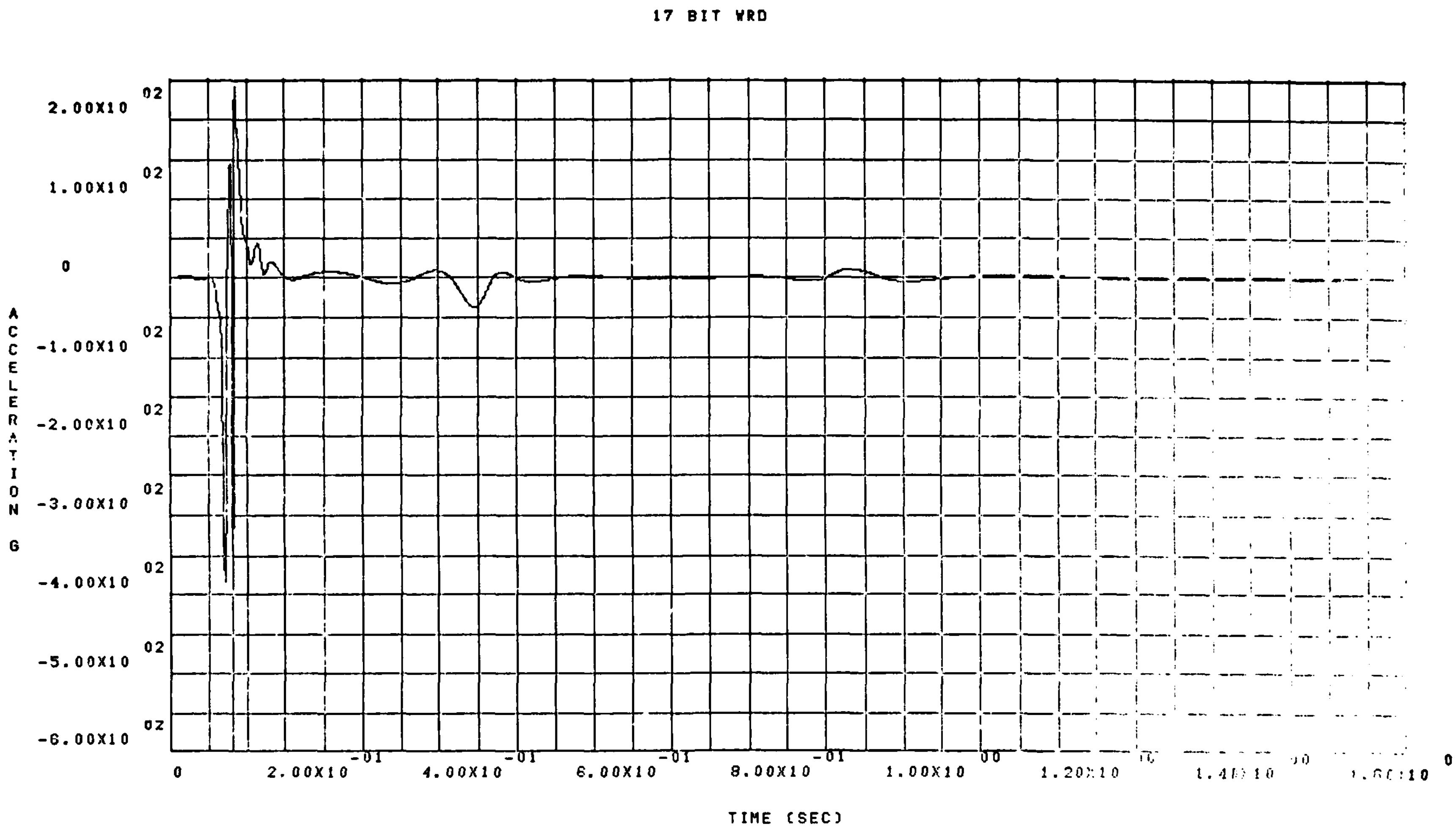

Figure 35. Acceleration vs time.
17 significant bits word size.

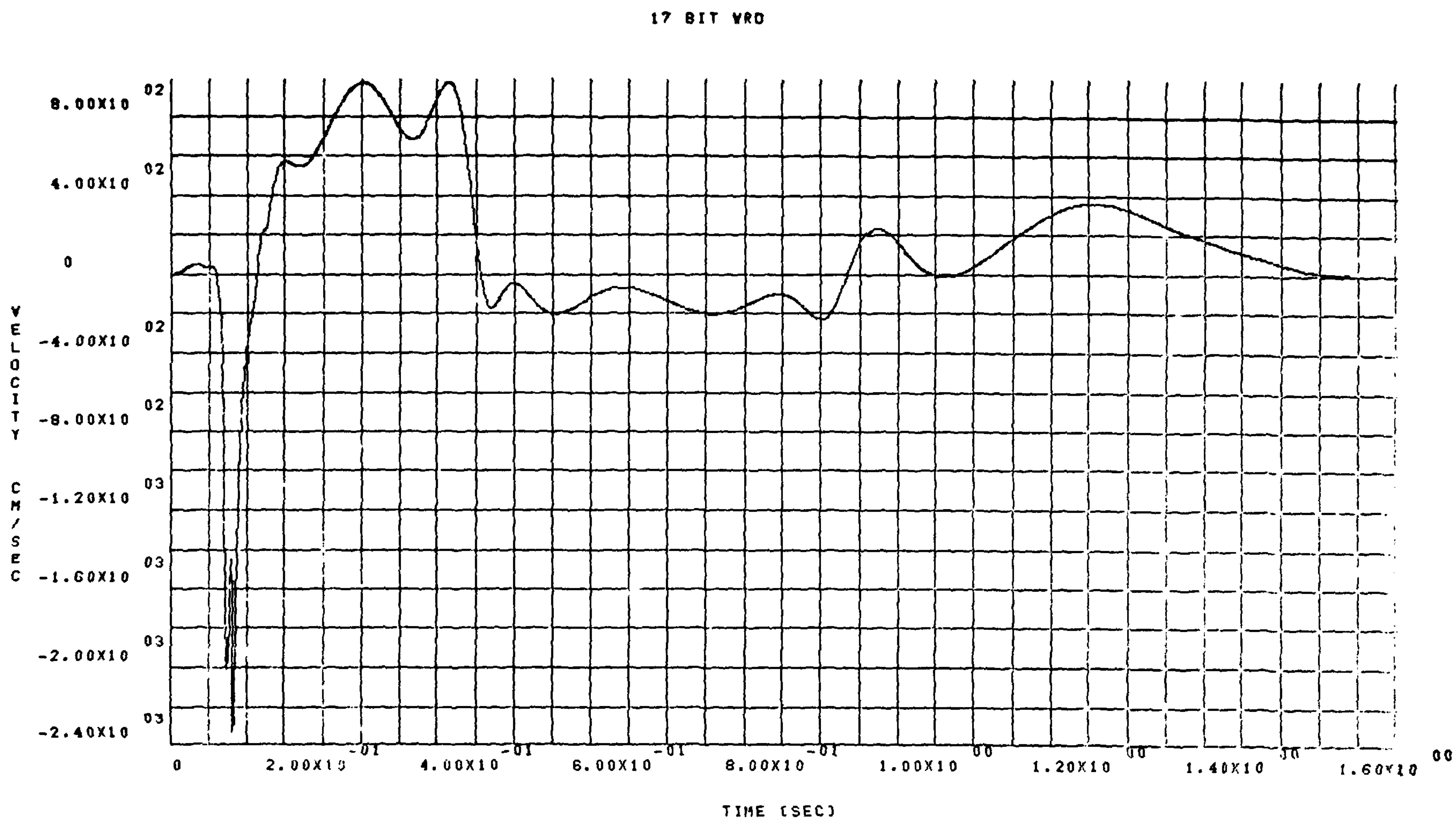

Figure 36. Velocity vs time.
17 significant bits word size.

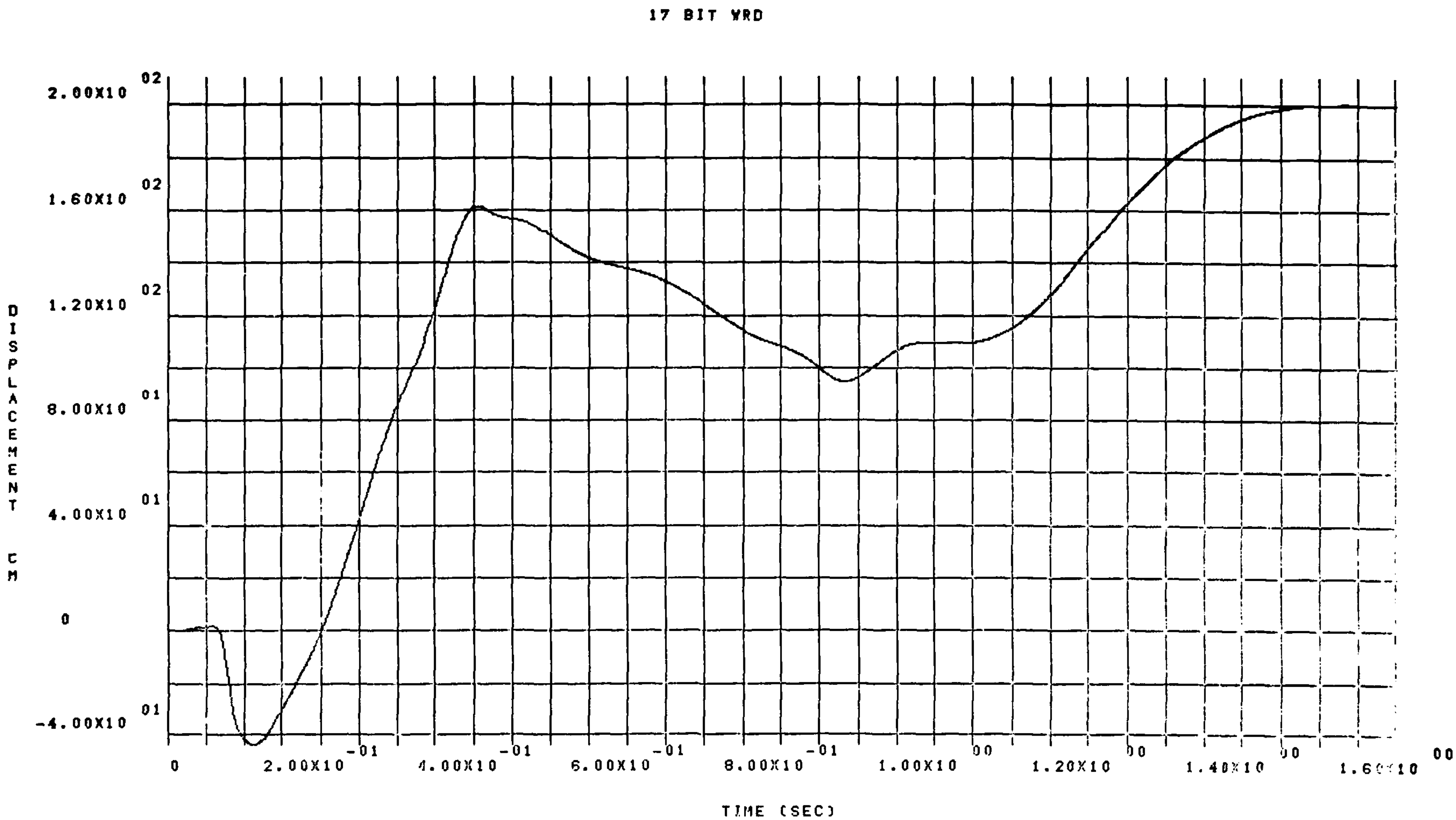

Figure 37. Displacement vs time.
17 significant bits word size.

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